c/o Asplan VIAK
Vestre Strandgate 27
4611 Kristiansand
Norway

Project Title: **Capacity-Building and Institutional Cooperation in the Field of Hydrogeology for Faryab Province, Afghanistan**

Report Title:

A Methodology for Provincial Hydrogeological Mapping in Afghanistan

Part 1: Methodology, Data Sources and Processing

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Abbreviations used in this report:

AGS = Afghan Geological Survey

AUWSSC = Afghan Urban Water Supply and Sewage Corporation (privatisation of CAWSS)

CAWSS = Central Authority for Water Supply and Sewage (reporting to MUDA). Now AUWSSC

FAO = Food and Agriculture Organization of the United Nations.

EC = electrical conductivity

IBE = ion balance error

m asl = m above sea level

meq/L = milliequivalents (of ionic charge) per litre

mg/L = milligrams per litre

mmol/L = millimoles per litre

mOD = metres above Ordnance Datum (i.e. above sea level)

m bgl = metres below ground level

m bwt = metres below well top

MAIL = Ministry of Agriculture, Irrigation and Livestock

MoEW = Ministry of Energy and Water

MoM = Ministry of Mines

MUDA = Ministry of Urban Development Affairs

MRRD = Ministry of Rural Rehabilitation and Development

RWL = rest water level (i.e. static groundwater level)

USGS = United States Geological Survey

WSG = Water and Sanitation Group (set up by UNICEF in Afghanistan)

Google Earth imagery used in this report. As our primary intention in using these images is ***not*** to present the Google Earth images themselves, but rather to use them as a geographical reference background on which we project our own data, we claim that this falls within the definition of “reasonable and fair use” of these images.

1 Objective

The objective of this report is to summarise a broad methodology for hydrogeological mapping at a Provincial level in Afghanistan.

The methodology is based on principles used by NORPLAN when carrying out hydrogeological mapping of Faryab Province in the period 2012-14, in the context of the project "*Capacity-Building and Institutional Cooperation in the Field of Hydrogeology for Faryab Province, Afghanistan*", funded by the Norwegian Government, via NORAD.

Methodologies for hydrogeological mapping will differ somewhat from region to region, as both climate and rock type vary considerably within Afghanistan. For example, while it may be possible to produce maps showing systematic and gradual trends in factors such as well-yield, water chemistry and water table level in areas underlain by extensive granular aquifers, this may not be possible in areas where most aquifers are fractured bedrock (granites, slates, limestones etc.). In the latter cases, a more probabilistic approach will usually be recommended. Such *non-parametric statistical approaches* have been pioneered in Scandinavia and the Czech Republic and can be found summarised, for example, in:

- **Banks, D., Morland, G. & Frengstad, B. (2005).** Use of non-parametric statistics as a tool for the hydraulic and hydrogeochemical characterization of hard rock aquifers. ***Scottish Journal of Geology***, 41(1), 69-79. doi 10.1144/sjg41010069

The objective of a hydrogeological survey is to ***characterise the groundwater resources of the area in terms of quantity (availability), depth and quality***.

The objective of a hydrogeological survey is **not** to simply produce a register of wells or water resources infrastructure. This is a management task and not a hydrological or geological task. Of course, a well-documented hydrogeological survey will contribute a lot of information to such a register (and *vice versa*), provided that the raw data are diligently documented and quality assured.

Any hydrogeological mapping should be undertaken in line with the broad principles enshrined in the guidelines of the **International Association of Hydrogeologists (IAH):**

- **Struckmeier, W.F. & Margat, J. (1995).** Hydrogeological maps: a guide and standard legend. ***International Contributions to Groundwater***, Vol. 17, International Association of Hydrogeologists, Heise, Hannover. Available at http://www.bgr.bund.de/EN/Themen/Wasser/Projekte/laufend/Beratung/Ihme1500/standard_legend_hydro_maps.pdf?__blob=publicationFile&v=1 and at http://iah.org/wp-content/uploads/2013/03/IAHbook_ICH17.zip.

See Appendix A.

1.1 Who should perform Hydrogeological Mapping

Hydrogeological mapping is fundamentally a scientific task, rather than an engineering or administrative task. Hydrogeological mapping should therefore be performed by an organisation with (a) good hydrological and geological field expertise and (b) a mandate to manage the groundwater resources of the country.

In Afghanistan, the logical organs to carry out hydrogeological mapping are therefore:

- The Ministry of Mines (MoM) and/or Afghan Geological Survey (AGS), or
- The Ministry of Energy and Water (MoEW)

The logical organisations to carry out inventories of wells and other water supply infrastructure are:

- The Ministry of Rural Rehabilitation and Development (MRRD) in respect of rural water supply infrastructure.
- The Ministry of Agriculture, Irrigation and Livestock (MAIL), in respect of agricultural water supply.
- The Ministry of Urban Development Affairs (MUDA) in respect of urban water supply infrastructure. This was formerly managed through the state-owned CAWSS enterprises, now privatised to form AUWSSC.

2 What is a Hydrogeological Map?

A hydrogeological map is a document (or, increasingly, a web-based GIS tool) that provides geographically-based information on the groundwater resources of an area. The information typically provided includes all or some of the following:

Geological

- The lateral outcrops of aquifers and aquitards, typically as shaded polygons.
    - Shading or contouring may also be used to show how the nature of the aquifer (granular or fractured) varies.
- Three-dimensional information on the vertical occurrence of aquifers and aquitards can also be conveyed. For example, concealed aquifers can be indicated by using a combination of shaded polygons (lateral extent of outcrop) and contours (depth of base and/or top in concealed area).
- The hydraulic properties of those aquifers, especially transmissivity.

Hydrological

- The groundwater level (or head), either as depth below ground surface, or as an absolute elevation (m above sea level). This is often shown by a series of contours.
- The groundwater quality (e.g. salinity or other parameters).
- The occurrence of rivers and lakes (flows, elevations, water quality) and how these interact with the groundwater system.
- Information on rainfall and groundwater recharge.

Survey (point) data

Although it is of the utmost importance to preserve the raw data used in constructing the map, it may not be desirable to show all this raw data on the map. (Increasingly, with GIS-based systems, raw data points can be shown or hidden at the click of a button). The raw data will usually be point data representing:

- Wells and boreholes (with attached water level, yield and quality data, and geological / construction data)
- Springs (with attached water level, discharge and quality data)
- Karezes (with attached water level, discharge and quality data, and construction data)
- Meteorological stations (with associated data)
- River flow gauging or sampling stations

2.1 Presentation of Data - Paper Maps

For many decades, the standard method of presenting geographically distributed hydrogeological data has been some form of paper-based map.

Differing formats have been used in different lands. However, some common features are often seen:

(i) Polygons / areas of different colour / shading are typically used to show aquifer or aquitard units of differing lithology.

(ii) Contours are typically used to illustrate (i) groundwater piezometric surface, (ii) top and bottom of aquifer, (iii) aquifer thickness.

(iii) Either shading or contours are used to illustrate groundwater quality factors:

- shading may be used to show areas where the groundwater is unacceptably saline or where nitrate concentrations exceed drinking water norms.
- contours may be used to illustrate, e.g., a progressive increase in groundwater salinity.

(iv) If hydraulic data are dense enough, shading or contours can be used to show regional variations in aquifer properties, such as transmissivity.

(v) Maps also often show the most important wells, boreholes and springs, either in terms of groundwater discharge or in terms of key information availability.

Soviet Maps

Typically, Soviet hydrogeological maps are extremely data-dense. Different "layers" of shading and contours are often combined on a single map. As a consequence, Soviet maps are extremely rich in information, but require a certain level of familiarity to interpret them. Perhaps the best known Soviet hydrogeological map of northern Afghanistan is that of Mishkin (1968)

- **Мышкин Л.П. (1968).** Схематическая карта гидроизогипси минерализации подземных вод четвертичных отложений центральной части Северного Афганистана. Масштаб 1:500,000 (*Schematic map if hydroisohypses of groundwater mineralization in the Quaternary deposits of the central part of northern Afghanistan. Scale 1:500,000*). Reproduced in black and white as Figure 16 in **Маринова, Н.А. (ed.) (1974)** Гидрогеология Азии *(Hydrogeology of Asia)*. Nedra, 576 pp.

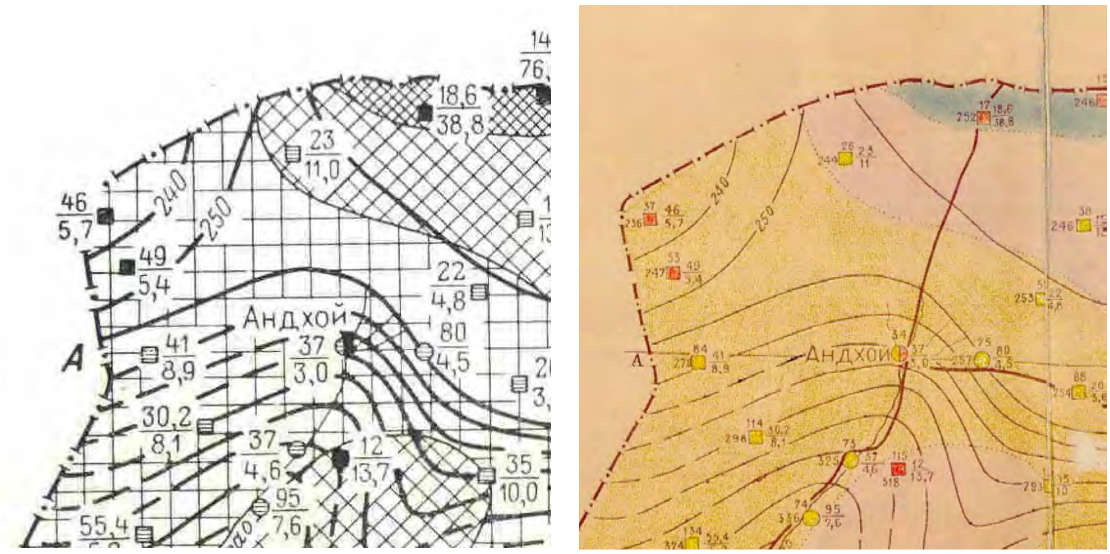


Figure 2.1*. In the map of Mishkin (1968), of the Quaternary aquifer system around Andkhoi, the shading shows differing concentrations of groundwater salinity in g/L, the contours show groundwater head elevation in m asl. The squares and circles show individual wells and boreholes, with the numerator showing the depth of occurrence (залегание) of the water and denominator the mineralization in g/L.*

Norwegian Maps

Relatively few hydrogeological maps have been produced in Norway. Perhaps the best example is that of Østmo (1976)

- **Østmo, S.R. (1976).** Øvre Romerike, grunnvann i løsavsetninger mellom Jessheim og Hurdalsjøen : hydrogeologisk kart *(Øvre Romerike, groundwater in superficial deposits between Jessheim and Hurdalssjøen: hydrogeological map. Scale 1:20,000)*. Oslo Universitetsforlag / Norges geologiske undersøkelse.

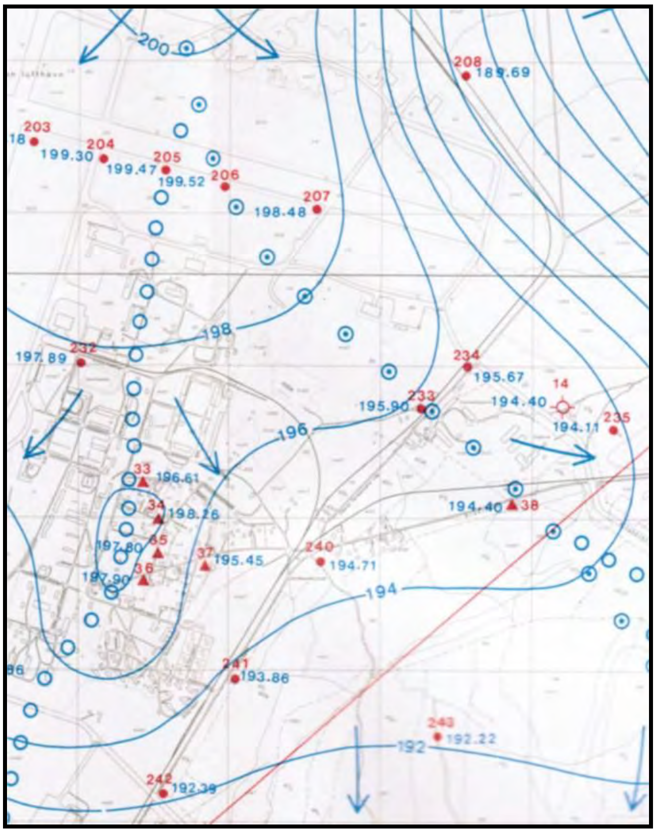


Figure 2.2. *An extract of the map by Østmo (1976) of the Øvre Romerike area, with contours showing water table elevation in m asl, small red dots/triangles showing locations of individual wells and lines of circles showing groundwater divides. Arrows show directions of groundwater flow.*

British Hydrogeological Maps

Especially in the 1970s and 1980s, the British Geological Survey published 1:100,000 hydrogeological maps of key aquifer units in the United Kingdom, in collaboration with the regional water utilities. Amongst these are:

- **IGS (1979).** *Hydrogeological Map of Hampshire and the Isle of Wight. Scale 1:100,000.* Institute of Geological Sciences and Southern Water Authority.
- **IGS (1980).** *Hydrogeological Map of East Yorkshire. Scale 1:100,000.* Institute of Geological Sciences and Yorkshire Water Authority.
- **BGS (1984).** *Hydrogeological map of the area between Cambridge and Maidenhead. Scale 1:100,000.* British Geological Survey, 1984.

The BGS maps are also relatively complex, using differing colours and shadings to distinguish the various aquifer / aquitard units, and with several sets of contours denoting groundwater heads in different aquifer units and structural contours on the top and base of the aquifer units.

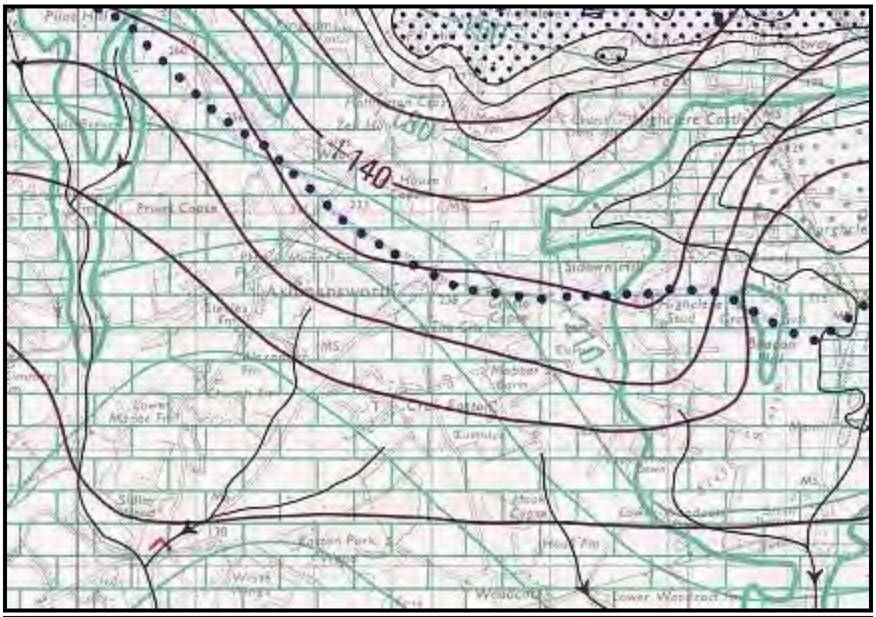


Figure 2.3. *A small extract of a published British hydrogeological map (Scale 1:100,000). Different shadings/colours show outcrops of different aquifer units. Purple contours show elevation of groundwater heads, green contours are structure contours on the top or base of aquifer formations.*

All the BGS hydrogeological maps are freely available to view at http://www.bgs.ac.uk/research/groundwater/datainfo/hydromaps/hydro_maps_scanviewer.html.

International Association of Hydrogeologists / UNESCO

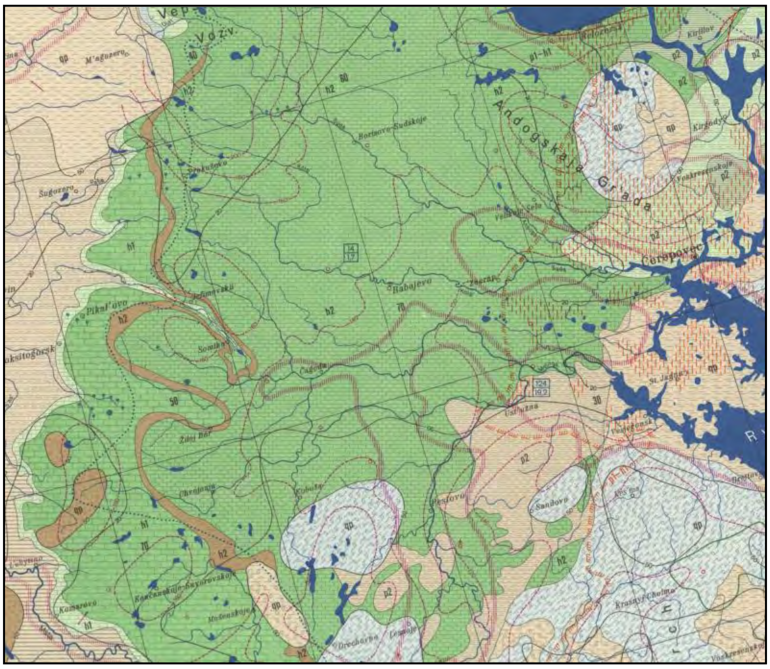


Figure 2.4. *An extract of the IAH/UNESCO 1:500,000 sheet for Moscow. Pale blue shows moderately/poorly productive granular aquifers; greens show fissured aquifers, browns show aquitards.*

The IAH / UNESCO have also published, in the 1970s and 1980s, a number of sheets of a 1:500,000 international hydrogeological map of Europe. These sheets are typically accompanied by an explanatory booklet. For example:

- **Persson, G., Kirkhusmo, L.A., Olsson, T. & Wikner, T. (1985).** *Explanatory notes for the hydrogeological map of Europe. Part 1. Sheet C2, Trondheim*. International Association of Hydrogeologists, UNESCO, Paris.

They all adhere to the IAH standard for hydrogeological mapping, which is reproduced in Appendix A. The maps are available at http://www.bgr.de/app/fishy/ihme1500/download.html.

The Geological Survey of China have commenced the production of a similar Hydrogeological Map of Asia, but currently, only overview 1:8,000,000 scale maps are available, at http://unesdoc.unesco.org/images/0022/002207/220768EO.pdf

- China Geological Survey (2012). *Groundwater Serial Maps of Asia: Hydrogeological Map, Groundwater Resources Map, Geothermal Map - Explanation*. Sinomaps Press, ISBN 978-7-5031-7398-1.

<u>Limitations of Paper-Based Maps</u>

(i) Paper maps are not good at showing three-dimensionality. In multi-layered aquifer systems, it becomes very challenging to show the properties and water levels in each aquifer horizon. Each aquifer horizon would often benefit from its own map sheet.

(ii) Paper maps cannot show three-dimensional head gradients. They assume that groundwater head / water table forms a single surface that can be contoured. In areas of high topography and low vertical hydraulic conductivity this may not be a good assumption.

(iii) Paper maps will always be interpretations: i.e., interpolations between individual data points. As more data become available, interpretations may change. A published map is an interpretation which can easily become “set in stone”, and where it is seldom possible to show all the raw data upon which the interpretation is based.

(iv) Hydrogeology can change with time. Groundwater levels and flow patterns can genuinely change with time, due to climate change and changes in abstraction patterns. Paper-based published maps may not keep pace with such changes.

2.2 Presentation of Data - WebGIS systems

Increasingly, WebGIS systems are being employed to surmount these issues:

(i) WebGIS makes data more freely available for users (at least, if those users are fortunate enough to own a computer and a good internet connection).

(ii) WebGIS can operate with layers, such that each aquifer unit in a 3-dimesnional aquifer system can be handled by its own layer of data.

(iii) Interpretations, groundwater patterns, areas of saline water etc. can be altered as new data and new interpretations become available. A WebGIS is not “set in stone”.

(iv) In theory, much, or all, of the raw data used to construct interpretative maps can be made available via the WebGIS (water analyses, hydrographs, borehole logs etc.).

This section will not deal with various WebGIS systems in detail, but will refer to four good examples of WebGIS systems and leave the reader to explore them him/herself.

International Association of Hydrogeologists / UNESCO Hydrogeological Map of Europe

This is a relatively simple hydrogeological map WebGIS, showing essentially only differently shaded polygons representing different aquifer units (see Appendix A).

It is also available for Google Earth at http://www.bgr.de/app/fishy/ihme1500/GE/ihme1500.kmz.

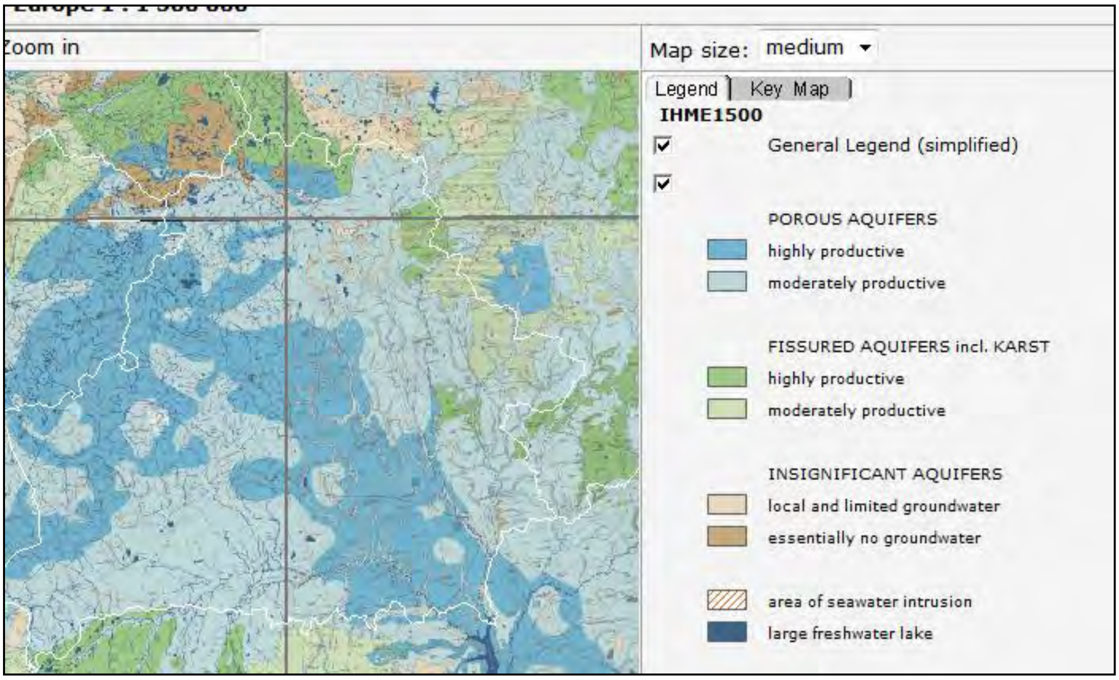


Figure 2.5. Screenshot of the IAH / UNESCO hydrogeological map of Europe, available at http://www.bgr.de/cgi-bin/ms481/mapserv.exe?java=off&map=f%3A%5Cwww%5CAnwendungen%5Cfishy%5Cihme1500%5Cihme1500.map&layer=Hydrogeo1&layer=sheet_index&layer=border&map_size=760+650

The Norwegian GRANADA System

The GRANADA database and WebGIS, hosted by the Geological Survey of Norway, shows

- geology
- groundwater potential
- information on individual boreholes and wells

The service is located at http://geo.ngu.no/kart/granada/

The tool does not attempt to show groundwater contours, or a great deal of interpretative hydrogeological information, but rather places emphasis on raw data availability.

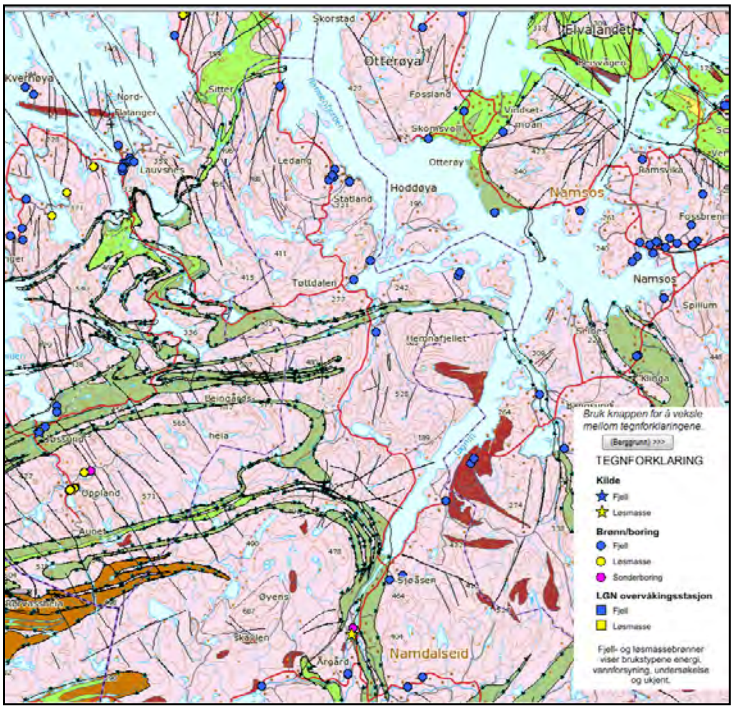


Figure 2.6. Screenshot of the GRANADA database, showing an area of Flatanger, Nord Trøndelag, with bedrock boreholes (blue circles), superficial deposit boreholes (yellow circles) and bedrock geology.

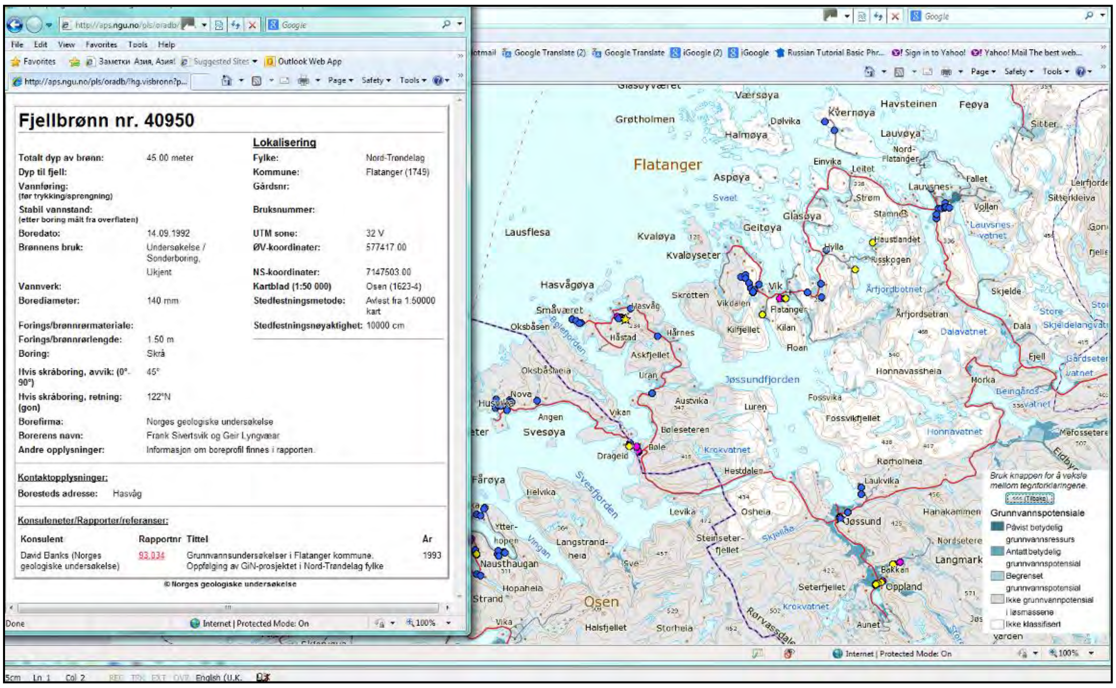


Figure 2.7. Screenshot of the GRANADA database, showing an area of Flatanger, Nord Trøndelag, with groundwater potential (grey = limited potential, shades of blue = varying potential, white = unclassified), boreholes (key as above) and a window showing drilling details for a specific borehole number 40950.

The Danish JUPITER System

The JUPITER database, hosted by the Geological Survey of Denmark and Greenland (GEUS), shows

- information on individual boreholes and wells, with all associated data and geological columns.

It does not attempt to show geology (probably because most of Denmark's' aquifers are concealed beneath varying deposits of superficial Drift and are not easily shown on a map) or any interpretative information on groundwater potential or depth. It places greater emphasis on raw data availability.

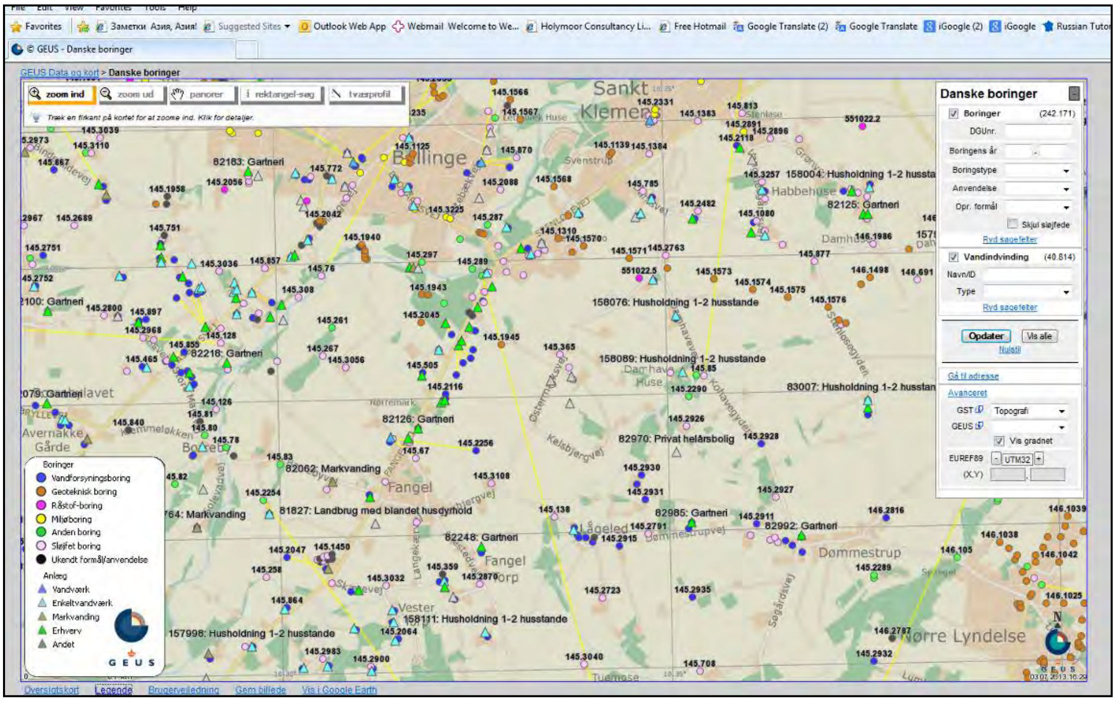


Figure 2.8. Screenshot of the JUPITER database, showing all available boreholes. Groundwater abstraction boreholes are shown as blue circles.

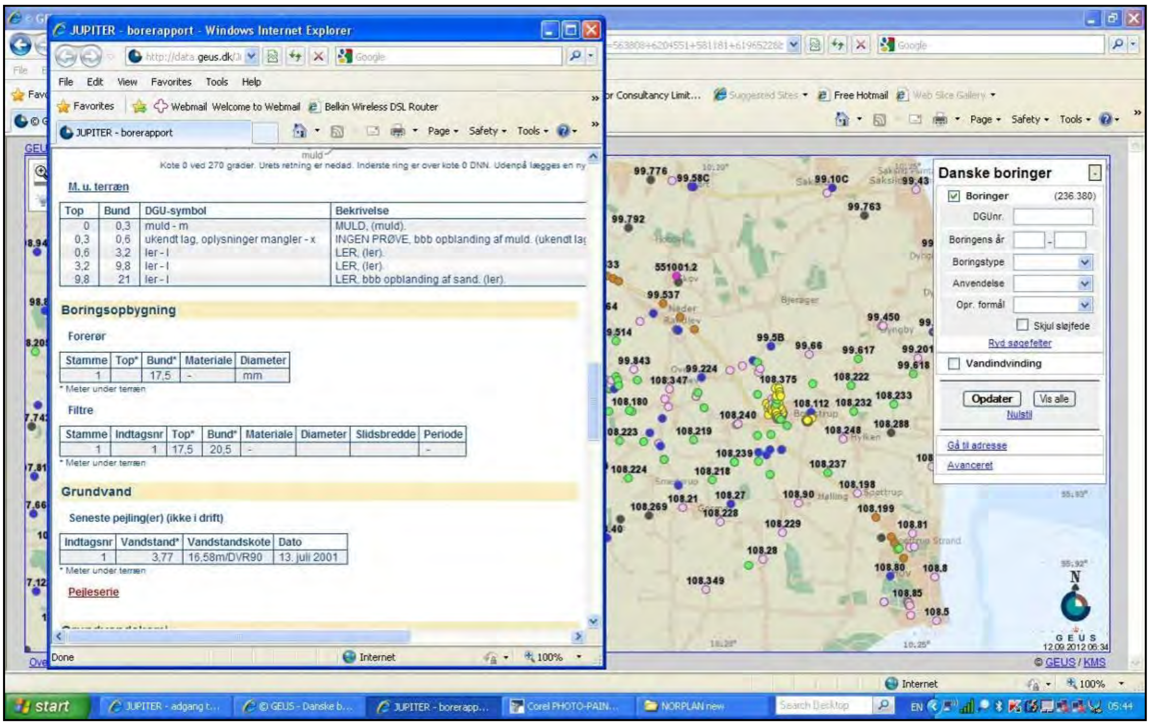


Figure 2.9. Screenshot of the JUPITER database, showing a sub-window with information associated with a specific well.

The service is located at http://geuskort.geus.dk/GeusMap/index_jupiter.jsp?imgxy=700+396&iMapWidth=1400&iMapHeight=791

It is also available as a Google Earth file at http://geuskort.geus.dk/googleearth.

Separate tools with geological maps and geological reports are found at

http://www.geus.dk/digital_data_maps/

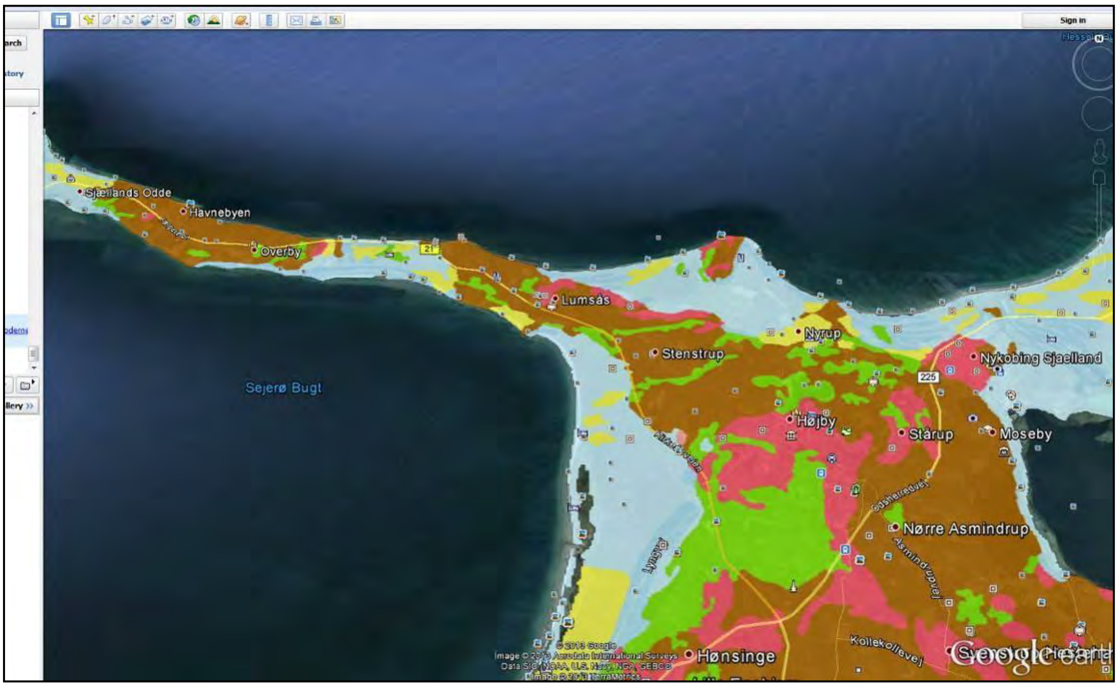


Figure 2.10. GEUS's geological map tool as seen in Google Earth.

British WebGIS Hydrogeological Tools

We have already seen that the British Geological Survey have made available the old hydrogeological maps sheets from the 1980s at http://www.bgs.ac.uk/research/groundwater/datainfo/hydromaps/hydro_maps_scanviewer.html.

The other main hydrogeological databases are as follows:

The Onshore GEOINDEX database

This is available at http://mapapps2.bgs.ac.uk/geoindex/home.html.

Amongst other things, it shows bedrock and superficial geology and all registered wells and boreholes in the country. The database also provides links to scans of original borehole logs (Figure 2.11).

Separate WebGIS tools are available that show

- the groundwater productivity of the UK's various aquifers, at http://mapapps.bgs.ac.uk/hydrogeologymap/hydromap.html
- current groundwater level status in the country http://mapapps.bgs.ac.uk/groundwatertimeline/home.html

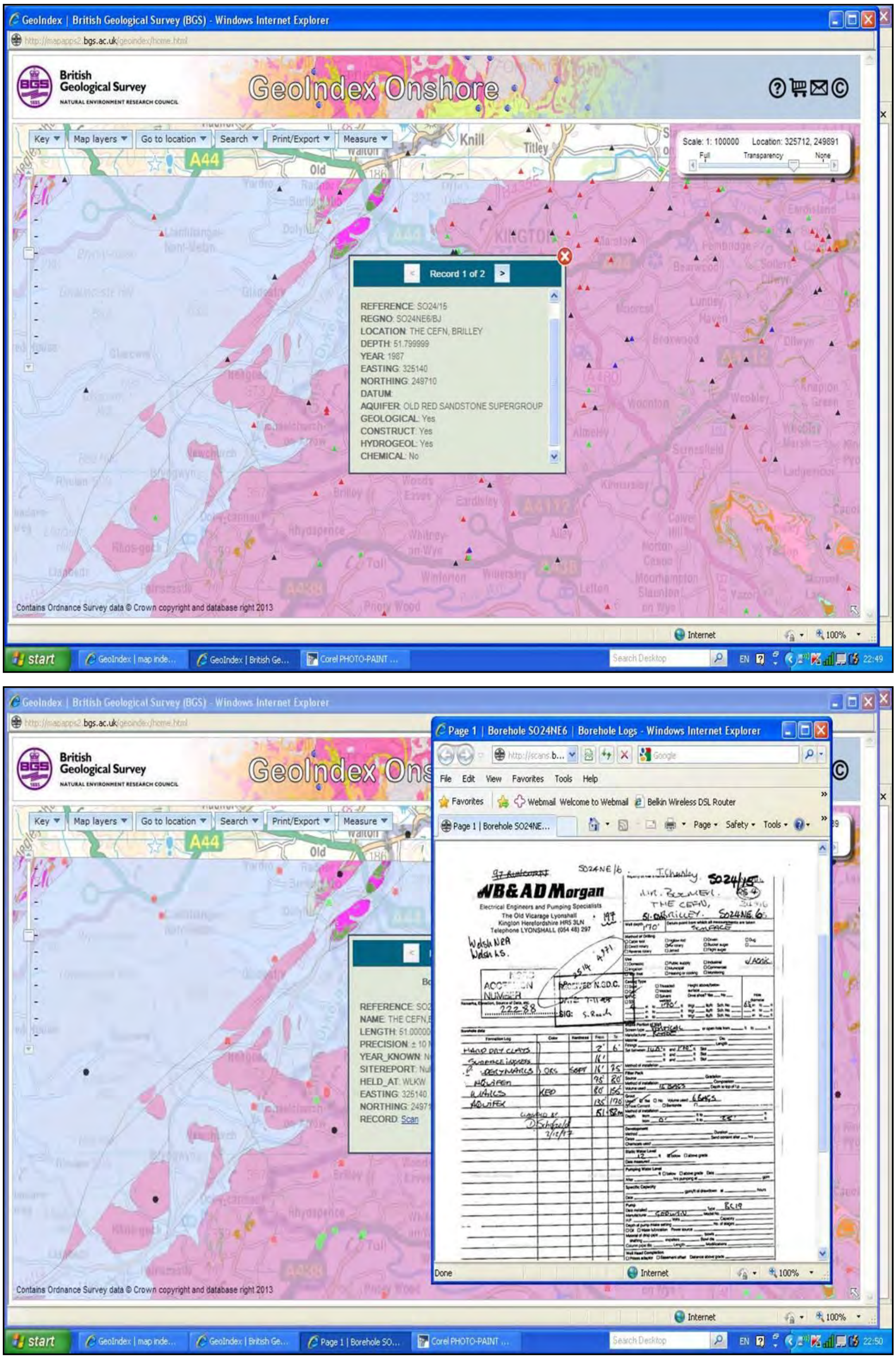


Figure 2.11. (top) BGS GeoIndex WebGIS tool, showing bedrock geology (coloured fields) and locations of wells and boreholes, together with well details held in database by clicking on one of the wells, **(bottom)** together with a link to the original scanned well log.

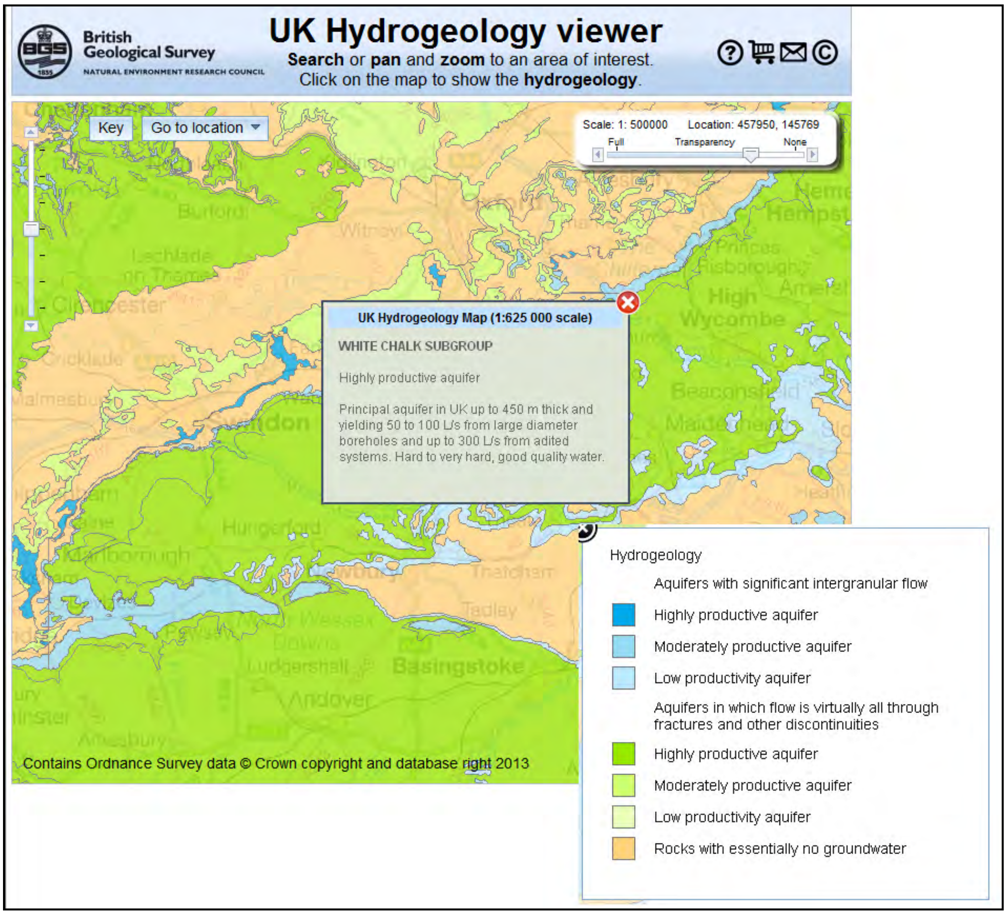


Figure 2.12. The UK hydrogeology viewer, hosted by BGS, shows aquifer outcrops in differing colours. Clicking reveals a description of the aquifer. Note that the legend follows the IAH recommendations (Appendix A).

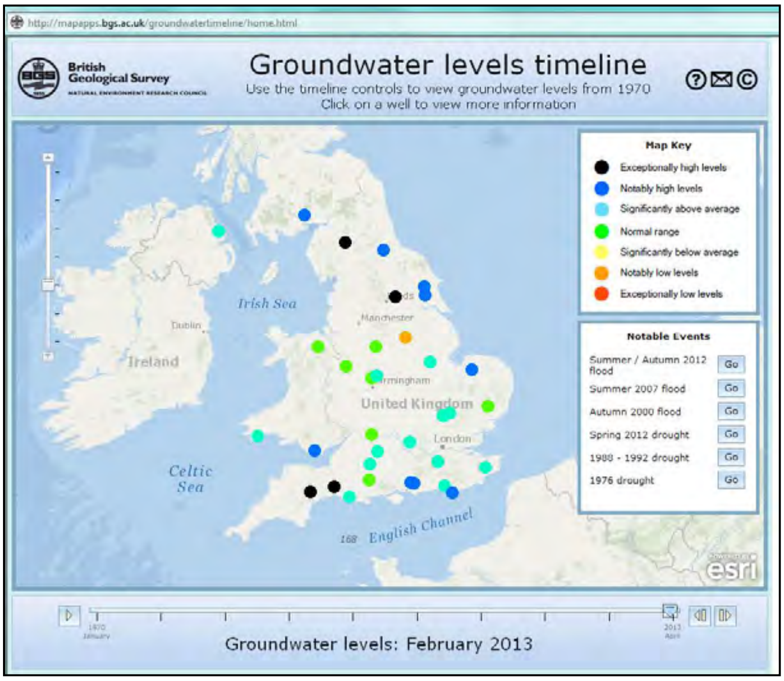


Figure 2.13. The UK groundwater levels viewer, hosted by BGS, shows that groundwater levels were generally rather high in February 2013.

Finally, the Environment Agency of England & Wales hosts a set of interactive WebGIS maps, one of which shows (a) aquifer classification, (b) source protection zones, (c) groundwater vulnerability zones. This tool is found at http://maps.environment-agency.gov.uk/wiyby/wiybyController?x=357683.0&y=355134.0&scale=1&layerGroups=default&ep=map&textonly=off&lang=_e&topic=groundwater.

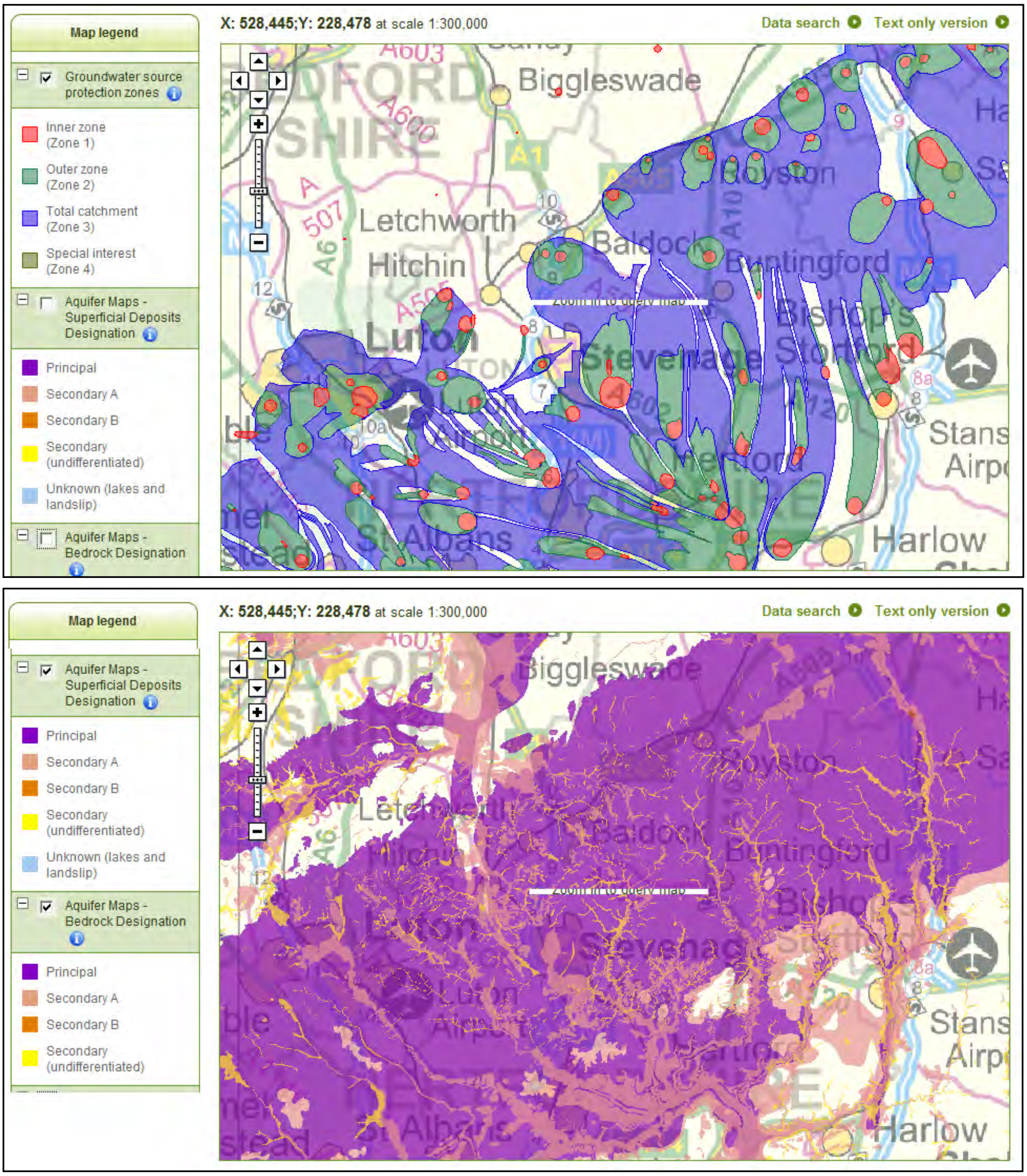


Figure 2.14. The Environment Agency's What's In My Backyard WebGIS tool, showing **(top)** inner (red), outer (green) and total catchment (blue) source protection zones for individual wells; and **(bottom)** aquifer classifications (primary, secondary etc.).

2.3 A Global Hydrogeological Map

The IAH hydrogeological mapping concept has been extended to a global scale at the www.whymap.org website. This WebGIS concept is run by BGR, the German geological survey and uses a variation of the International Association of Hydrogeologists' mapping legend.

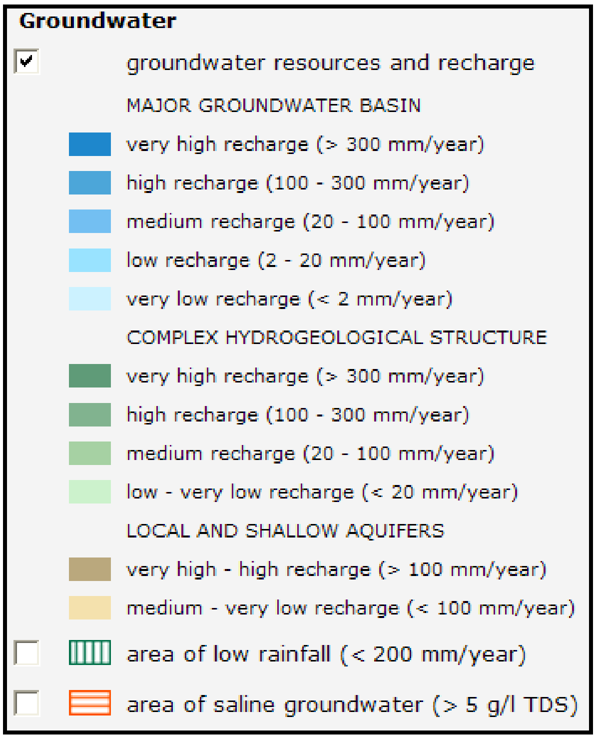


Figure 2.15. The global WHYMAP hydrogeological map legend.

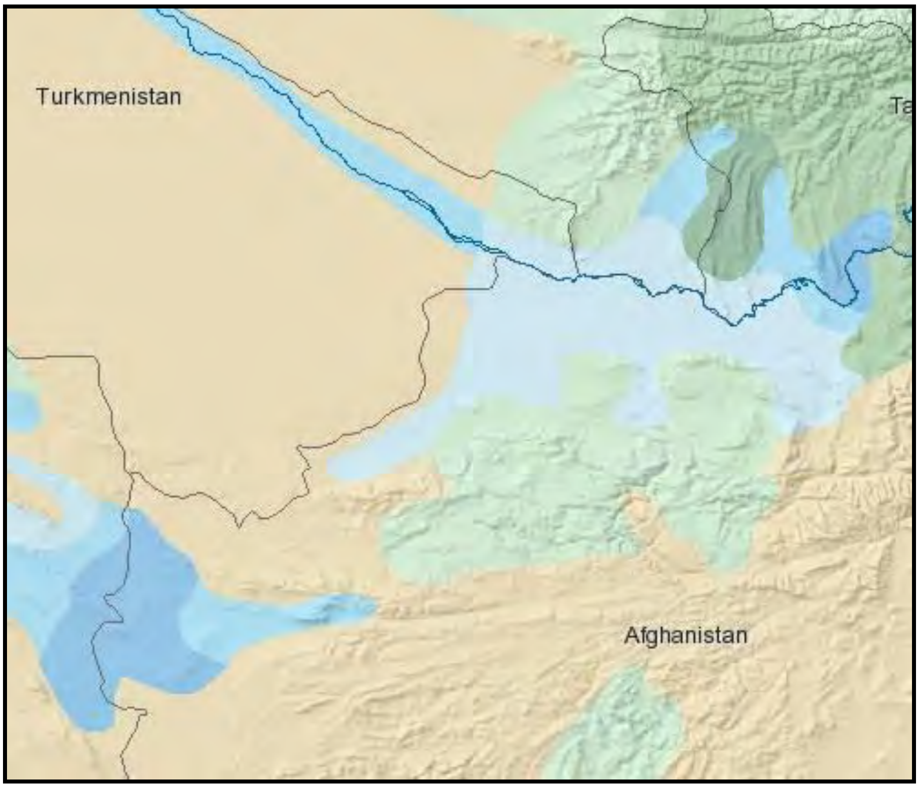


Figure 2.16. WHYMAP excerpt for north-western Afghanistan

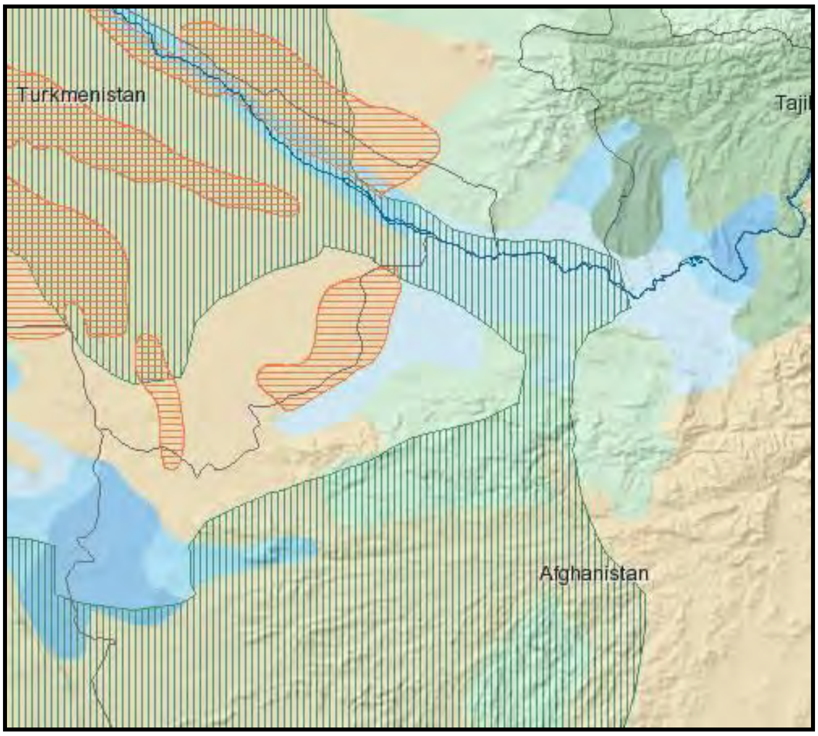


Figure 2.17. WHYMAP excerpt for north-western Afghanistan, showing areas of saline groundwater and low precipitation.

3 A Plea for Open Data

Information = power

If a public authority has as its ambition to maintain power and earnings for itself, it should restrict access to the data it holds and charge for access to that data.

If a public authority has as its ambition to spread power, encourage a freely competing and collaborating private / NGO sector and to facilitate the greatest possible use of data that, ultimately, has often been paid for by domestic public taxes or foreign public donors, then it should aim to make its data as freely available as possible, via the internet.

This applies not just to interpretations of data (because state experts can also be wrong!), but to the raw data itself.

NORPLAN would thus strongly encourage the release of raw hydrogeological data to the World Wide Web for the use of all: NGO, private sector, researchers and state authorities. NORPLAN has been committed to this principle throughout the hydrogeological mapping of Faryab Province.

For a country such as Afghanistan, the dissemination of data and maps need not be restricted to a single forum. Indeed, consideration should be given to providing hydrogeological mapping data via:

- A comprehensive GIS database within the authority responsible for that data, linked to:
- A public WebGIS tool, providing access to maps, interpretations of data and, most importantly, raw data itself.
- A Google Earth tool, allowing the data to be accessed via the alternative medium of Google Earth.
- More conventional paper-based reports and maps, for the benefit of those without access to computers and the Internet.

4 Sources of Background Mapping Data

In this context, background mapping data is taken to include:

1. Topographic / terrain elevation data
2. Political data (province / district boundaries, major towns and cities)
3. Other topographic data (road network)
4. Geological outcrops, faults and contacts
5. Outcrops of hydrogeological units (aquifers and aquitards)
6. Hydrological data (river network)
7. Meteorological data

Much of the fundamental background data will already be available either via the relevant Afghan Ministries, or from one of two data sources resulting from recent collaboration between the Afghan Geological Survey and the United States Geological Survey:

1) The USGS Afghanistan website at http://afghanistan.cr.usgs.gov/geospatial-reference-datasets.
2) CD-ROMs and data provided with USGS Open File reports 2006-1038 and 2006-1179, also available at http://pubs.usgs.gov/of/2006/1179/Data_layers.html.

4.1 Topographic / elevation data

Various digital elevation models are available from the USGS Afghanistan website at http://afghanistan.cr.usgs.gov/geospatial-reference-datasets.

4.2 Political data

Numerous data sets exist on the internet showing province and district boundaries. At present, good Google Earth files can be found at

Provinces: http://geocommons.com/maps/50121,

http://geocommons.com/overlays/23585

Districts: http://geocommons.com/maps/85379,

http://geocommons.com/maps/86639,

The locations of major towns and cities can readily be digitised from Google Earth.

4.3 Other topographic data (roads)

Shape files containing road data can be found in the USGS Open File Reports, or from various internet sources.

4.4 Geological Outcrops, Faults and Contacts

NORPLAN recommends the use of the USGS 1:250,000 map series, found in pdf format at http://afghanistan.cr.usgs.gov/afghan_geo.php as the appropriate level of detail for Provincial Scale hydrogeological mapping in Afghanistan.

Shape files of (i) the geological polygons, (ii) contacts and (iii) faults (iv) dykes at this scale can be found in the USGS Open File Reports cited above or at http://pubs.usgs.gov/of/2006/1179/Data_layers.html.

Additional files can be added, such as structural contour files of specific geological units. For example, for the Faryab mapping, we have made use of the following files:

- Contours on top of Ghory Formation (m asl): Contours of sub-sea depth (in meters) of the Palaeogene Ghory Formation in northern Afghanistan. http://pubs.usgs.gov/of/2006/1179/shapezip/ghorydpafg.zip
- Contours on top of Qezeltash Formation (m asl): Contours of sub-sea depth (in meters) of top of Hauterivian sandstones (Qezeltash Formation) in northern Afghanistan. http://pubs.usgs.gov/of/2006/1179/shapezip/qezeldpafg.zip

4.5 Outcrops of Hydrogeological Units

Hydrogeological units will be based on the outcrops of geological units (see 4.4), but with each unit re-coloured and re-described according to the IAH Guidelines for hydrogeological mapping (Appendix A). The classification of geological unit as good / poor / intergranular / fractured / karst aquifers is best done in a workshop environment involving hydrogeologists with field experience in the area in question.

4.6 Rivers and Surface Waters

The USGS data sources have basic outlines of Rivers as line files for GIS environments.

In Faryab, however, it has been found preferable to “trace” surface waters in the Google Earth environment, to save them as kml or kmz files and then import them into the relevant GIS environment.

4.7 Meteorological data

Arguably, the best regional sources of meteorological data are found at the NOAA website http://www.esrl.noaa.gov/psd/data/gridded/data.ghcncams.html (temperature) / http://www.esrl.noaa.gov/psd/data/gridded/data.gpcc.html (precipitation)

For air temperature, we would tentatively suggest using the file ftp://ftp.cdc.noaa.gov/Datasets/ghcncams/Derived/air.mon.1981-2010.ltm.nc. This represents long-term gridded monthly means, based on data from 1981-2010, on a 0.5 degree latitude x 0.5 degree longitude global grid (360x720), from the GHCN_CAMS Gridded 2m Temperature (Land) data set.

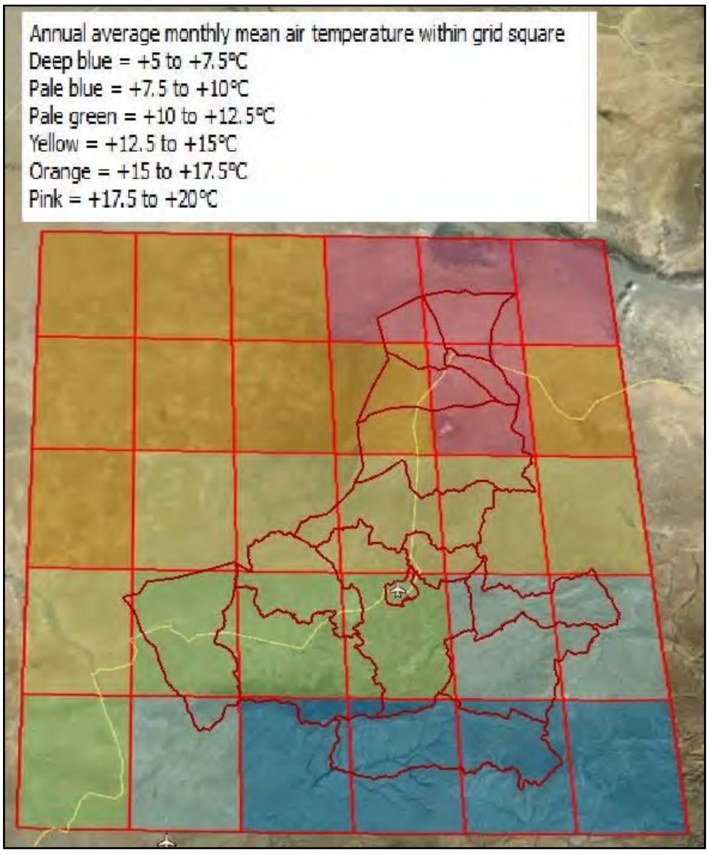
- Fan, Y., & H. van den Dool (2008). A global monthly land surface air temperature analysis for 1948-present, J. *Geophys. Res.* **113**, D01103, doi:10.1029/2007JD008470

For precipitation, we would tentatively suggest using the file ftp://ftp.cdc.noaa.gov/Datasets/gpcc/full_v6/precip.mon.1981-2010.ltm.v6.nc. This represents long-term gridded monthly means, based on data from 1981-2010, on a 0.5 degree latitude x 0.5 degree longitude global grid (180x720), from the GPCC Global Precipitation Climatology Centre data set.

- Schneider, U., Becker, A., Finger, P., Meyer-Christoffer, A., Rudolf, B., Ziese, M. (2011). GPCC Full Data Reanalysis Version 6.0 at 0.5°: Monthly Land-Surface Precipitation from Rain-Gauges built on GTS-based and Historic Data. DOI: 10.5676/DWD_GPCC/FD_M_V6_050

Thus, each data point in these sets can be taken as a central point, roughly representing a 0.5° x 0.5° area. In a WebGIS solution, one can therefore represent these as gridded overlays, colour coded according to annual precipitation or annual mean air temperature (Figure 4.1).

In a WebGIS solution, the user should be able to click on one of the rectangles to bring up the raw data, including a graph of the data for the 0.5° x 0.5° grid square in question (Figure 4.2).



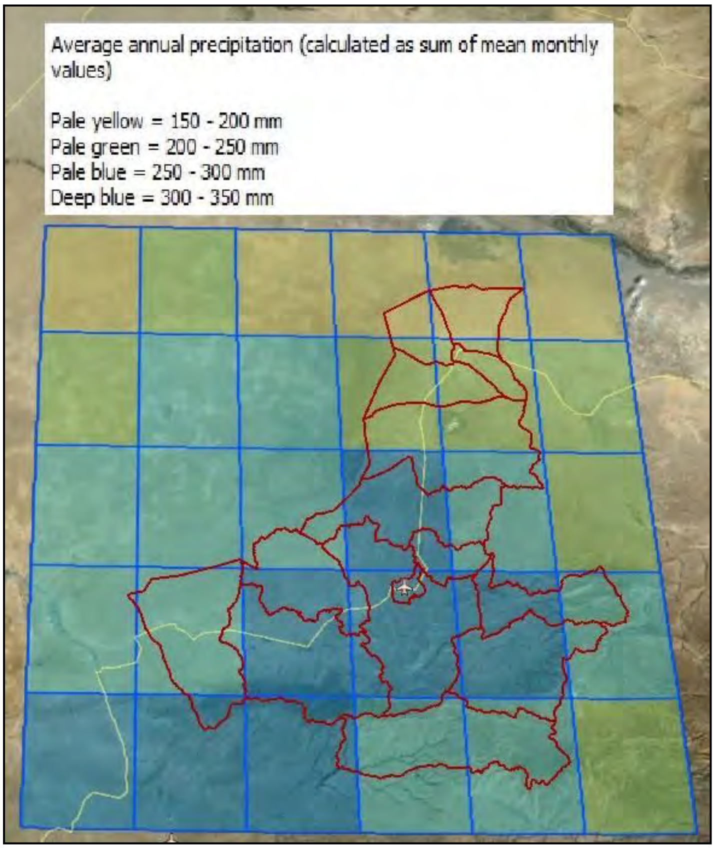
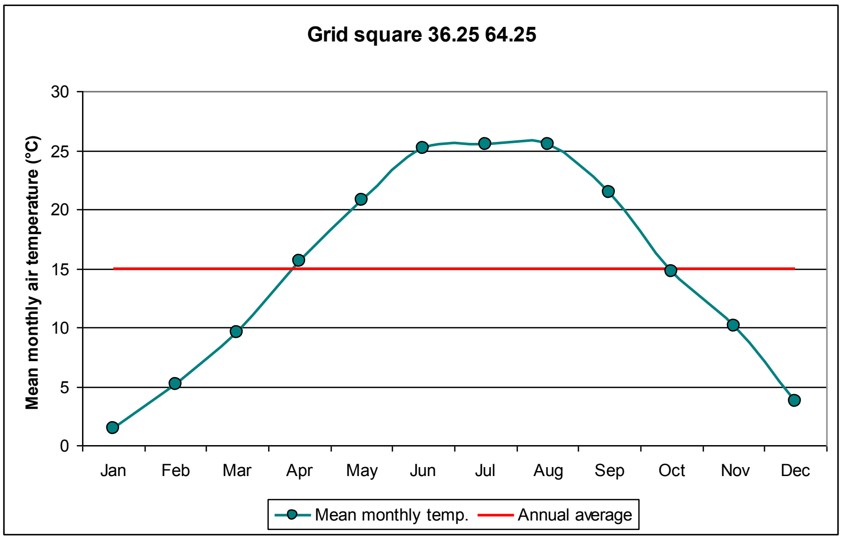
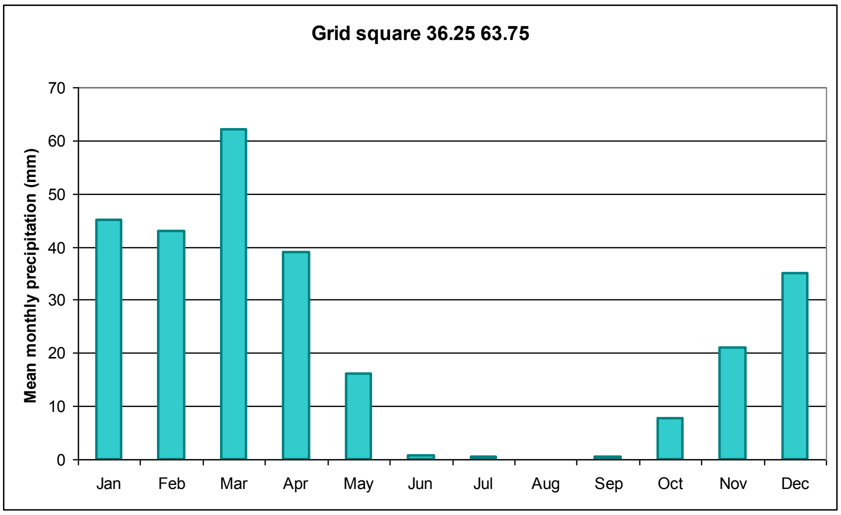


Figure 4.1. Grids of (top) annual average air temperature and (below) average total annual precipitation, for Faryab, based on the NOAA data described in Section 4.7.



Mean Monthly temperature	
Jan	1.4
Feb	5.2
Mar	9.6
Apr	15.6
May	20.8
Jun	25.2
Jul	25.4
Aug	25.5
Sep	21.5
Oct	14.7
Nov	10.1
Dec	3.8
Annual average	**14.9**



Mean monthly precipitation (mm)	
Jan	45
Feb	43
Mar	62
Apr	39
May	16
Jun	0.73
Jul	0.37
Aug	0.013
Sep	0.41
Oct	7.6
Nov	21
Dec	35
Annual total	**270.1**

Figure 4.2. Examples of data that should be accessible by clicking on one of the 0.5°x 0.5° meteorological grid squares in the WebGIS environment.

Other maps showing meteorological data also exist for Afghanistan. especially those available from the 1984 National Atlas of the Democratic Republic of Afghanistan, produced by the Afghan and the Polish Geodesy and Cartography Head Offices, assisted by UNDP, and available from the Afghan Information Management Services (AIMS) at http://www.aims.org.af/ssroots.aspx?seckeyt=391.

The FAO Aquastat tool also provides an excellent means of accessing climatic data (including potential evapotranspiration), at http://www.fao.org/nr/water/aquastat/gis/index3.stm.

5 Literature Review

The first step of any hydrogeological survey or mapping should be to find out what is already known and published about the geology and hydrology of the region in question.

In a region which is undergoing significant hydrogeological stress, such as Afghanistan, historical sources are especially useful. You may have heard rumours that the water quality in a particular region has deteriorated, that water used to be abundant and is now scarce, that rivers used to flow longer and further than they do now. Works or maps which were written decades or centuries ago will be especially useful in confirming or contradicting these claims. In Faryab, for example, Norplan found the following historic travel books of benefit:

- Vámbéry, A. (1865). *Reise in Mittelasien von Teheran durch die Turkmanische Wüste an der Ostküste des Kaspischen Meeres nach Chiwa, Bochara und Samarkand ausgeführt im Jahr 1863. [Travels in Central Asia from Teheran through the Turkman Deserts on the east side of the Caspian Sea towards Chiwa, Bochara and Samarkand].* Brodhaus, Leipzig.
- Byron, R. (1937). *The Road to Oxiana*. Macmillan.

Historic maps of Afghanistan can also be found at several localities on the internet: for example

- Ramusio's 1540 Map of Tartary at http://www.agefotostock.com/en/Stock-Images/Rights-Managed/DAE-11237002
- Kitchin's 1747 Map of Central Asia at http://www.geographicus.com/P/AntiqueMap/WesternTartary-kitchin-1747
- Postlethwayte's 1755 map at http://www.geographicus.com/P/AntiqueMap/AsiaWest-postlethwayte-1755
- Schraembl's 1786 map at http://www.geographicus.com/P/AntiqueMap/Persia-schraembl-1786
- Pinkerton's 1811 map at http://www.geographicus.com/P/AntiqueMap/Persia-pinkerton-1811
- Black's 1851 map at http://www.geographicus.com/P/AntiqueMap/Persia-black-1851

Each province of Afghanistan will have its own scientific literature on geology and hydrogeology and should be searched for individually. However, a selection of good, general, useful references is as follows:

- Abdullah, S.H. & Chmyriov, V.M. (eds.) (2008). *Geology and Mineral Resources of Afghanistan*. 2 volumes. British Geological Survey Occasional Publication No.15.
- Ahmad, M. & Wasiq, M. (2004). *Water Resource Development in Northern Afghanistan and its Implications for Amu Darya Basin*. World Bank Working Paper No. 36.
- Ashworth, J.M. (2005). *Groundwater Assessment of the Downstream Sections of the Balkh and Khulm Watersheds. Inception Report*. Ministry of Energy and Water, 2005.
- Banks, D. (2001). *Guidelines for Sustainable Use of Groundwater in Afghanistan*. Report for Norwegian Church Aid. http://www.holymoor.co.uk/Poldok.PDF.
- Banks, D. & Soldal, O. (2002). Towards a policy for sustainable use of groundwater by non-governmental organisations in Afghanistan. *Hydrogeology Journal* **10**, 377-392.
- Berg, L.S. (1950). *Natural Regions of the USSR*. Translated from the Russian by O.A. Titelbaum and edited by J.A. Morrison and C. C. Nikiforoff, MacMillan, New York.

- BGS (2013). *Geology of Afghanistan.* http://www.bgs.ac.uk/afghanminerals/geology.htm.
- Boomer, I., Aladin, N., Plotnikov, I. & Whatley, R. (2000). The palaeolimnology of the Aral Sea: a review. *Quaternary Science Reviews* **19,** 1259-1278.
- Breckle, S.W. (1983). Temperate deserts and semi-deserts of Afghanistan and Iran. Pages 271-319 *in:* West, N.E. (ed.) *Temperate deserts and semi-deserts.* Elsevier, Amsterdam.
- Brookfield, M.E. & Hashmat, A. (2001). The geology and petroleum potential of the North Afghan platform and adjacent areas (northern Afghanistan, with parts of southern Turkmenistan, Uzbekistan and Tajikistan). *Earth-Science Reviews* **55**, 41–71.
- CAWater (2012). *Hydrogeology and groundwater.* http://www.cawater-info.net/afghanistan/groundwater.htm
- DACAAR (2011). *Update on "National Groundwater Monitoring Wells Network activities in Afghanistan". From July 2007 to December 2010.* DACAAR Report, Kabul.
- Favre, R. & Kamal, G.M. (2004) *Watershed Atlas of Afghanistan. 1st Edition: Working Document for Planners.* Ministry of Irrigation, Water Resources and Environment, FAO, SDC, AIMS and AREU.
- Hassan Saffi, M. (2007). *Groundwater at risk in Afghanistan.* DACAAR Report, Kabul.
- Hassan Saffi, M. (2011). *Groundwater natural resources and quality concern in Kabul Basin, Afghanistan.* DACAAR Report, Kabul.
- Klemm, W. & Shobair, S.S. (2010) *The Afghan Part of the Amu Darya Basin. Impact of Irrigation in Northern Afghanistan on Water Use in the Amu Darya Basin.* http://www.unece.org/fileadmin/DAM/SPECA/documents/ecf/2010/FAO_report_e.pdf.
- Klett, T.R., Ulmishek, G.F., Wandrey, C.J. Agena, W.F. (2006). Assessment of undiscovered technically recoverable conventional petroleum resources of Northern Afghanistan. *U.S. Geological Survey Open-File Report* **2006-1253**.
- Nathan Berger (1992). *Afghanistan Water Constraints. Overview Analysis.* Report submitted to the Office of the A.I.D. Representative for Afghanistan Affairs by Nathan Associates Inc. and Louis Berger International, Inc.
- Oberhänsli, H., Novotná, K., Píšková, A., Chabrillat, S., Nourgaliev, D.K., Kurbaniyazov, A.K. & Grygar, T.M. (2011). Variability in precipitation, temperature and river runoff in W Central Asia during the past ~2000 yrs. *Global and Planetary Change* **76**, 95–104.
- Qureshi, A.S. (2002). *Water Resources Management in Afghanistan: The Issues and Options.* International Water Management Institute, Working Paper 49, Pakistan Country Series No. 14.
- Rakhmatullaev, S., Huneau, F., Kazbekov, J., Le Coustumer, P., Jumanov, J., El Oifi, B., Motelica-Heino, M. & Hrkal, Z. (2010). Groundwater resources use and management in the Amu Darya river basin (Central Asia). *Environmental Earth Sciences* **59**, 1183-1193.
- Rout, B. (2008). *How the Water Flows: A Typology of Irrigation Systems in Afghanistan.* Afghanistan Research and Evaluation Unit (AREU).
- Rycroft, D.W. & Wegerich, K. (2009). The three blind spots of Afghanistan: water flow, irrigation development, and the impact of climate change. *China and Eurasia Forum Quarterly* **7(4),** 115-133.

- Shobair, S.S. (2001) *Irrigation water management – crop water requirements*. Food and Agriculture Organisation of the United Nations (FAO), Peshawar (Pakistan), June, 111 pp.
- Shobair, S.S. & Alim, A.K. (2004). *The effects of calamities on water resources and consumption in Afghanistan*. Food and Agriculture Organization of the United Nations (FAO).
- Tünnermeier, T., Houben, G. & Niard, N.; edited by Himmelsbach, T. (2005 / 2006). *Hydrogeology of the Kabul Basin* (3 parts). Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Hannover, Germany.
- Uhl, V.W. & Qasem Tahiri, M. (2003). Afghanistan. An overview of groundwater resources and challenges. Uhl, Baron, Rana & Associates, Inc. http://www.vuawater.com/Case-Study-Files/Afghanistan/Afghanistan_Overview_of_GW_Resources_Study-2003.pdf.
- Ulmishek, G.F. (2004). *Petroleum Geology and Resources of the Amu-Darya Basin, Turkmenistan, Uzbekistan, Afghanistan, and Iran*. U.S. Geological Survey Bulletin 2201–H.
- USAID (1976). *Helmand River Basin. Soil and Water Survey Study Report*. Government of Afghanistan and USAID.
- Whitney, J.W. (2006). *Geology, Water, and Wind in the Lower Helmand Basin, Southern Afghanistan*. U.S. Geological Survey Scientific Investigations Report 2006–5182
- Zonn, I.S. (2002). *Water resources of Northern Afghanistan and their future use*. Paper presented at workshop on water, climate and development issues in the Amu-Dar'ya basin, Philadelphia, PA, 2002.
- Zonn, I.S., Kostianoy, A.G., Kosarev, A.N. & Glantz, M.H. (2010). *The Caspian Sea Encyclopedia*. Springer-Verlag, Berlin / Heidelberg.

6 Soviet Sources of Hydrogeological Data

6.1 Topographic maps

Full sets of Soviet topographic maps are available freely on the Internet[1]. Information can be extracted from these maps on

- the location of wells and boreholes (and other water supplies)
- groundwater quality
- well yield
- the location of springs
- the names, elevations and widths of rivers

A full key to Soviet topographic maps can be found in:

- Department of the Army (1958). *Soviet Topographic Map Symbols*. Department of the Army Technical Report **TM30-548**. United States War Office, June 1958. http://afghanistan.cr.usgs.gov/downloadfile2.php?file=Soviet_Map_Legend.pdf.

During the NORPLAN hydrogeological mapping of Faryab, it has been found that the 1:200,000 scale Soviet maps show adequate detail - each grid square is 4 km x 4 km. The map sheets have been systematically examined and all data on wells and springs has been abstracted and transferred to a standard format spreadsheet. To obtain grid references, the map sheets were overlain on Google Earth.

Key features that can be noted on such maps

Springs are shown as small blue circles with squiggly tails, and may be marked

роб. = родник or *ист.* = источник

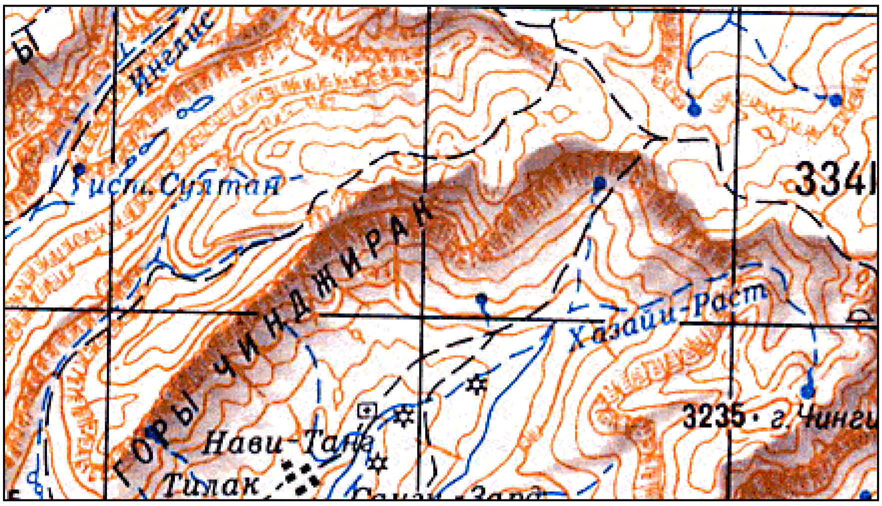


Figure 6.1. Extract of a Soviet 1:200,000 map showing am intermittent stream (dashed blue line) and several springs, including the Sultan Istochnik (Sultan Spring)

Wells (and also boreholes used for water supply) are typically marked

к. = колодец

Boreholes (for water supply or exploratory purposes) may also be marked

[1] For example at http://gigapan.com/gigapans/130196 or http://maps.vlasenko.net/soviet-military-topographic-map/map200k.html or http://topmap.su/indexn.html. Take a little observant with some of these websites re. malware.

скв. = скважина

Wells are typically marked with a blue circle, containing a small blue dot (or a larger dot for key wells).

Water quality may be marked as

сол. = соленая (salty) or *г.-сол.* = горько-соленая (bitter salty)

The well name may be followed by a depth *гл.* = глубина (170 m in the case of Moscow well in Figure 6.2), and a statement of yield

наполн. = filling / yield *л/ч* = litres per hour

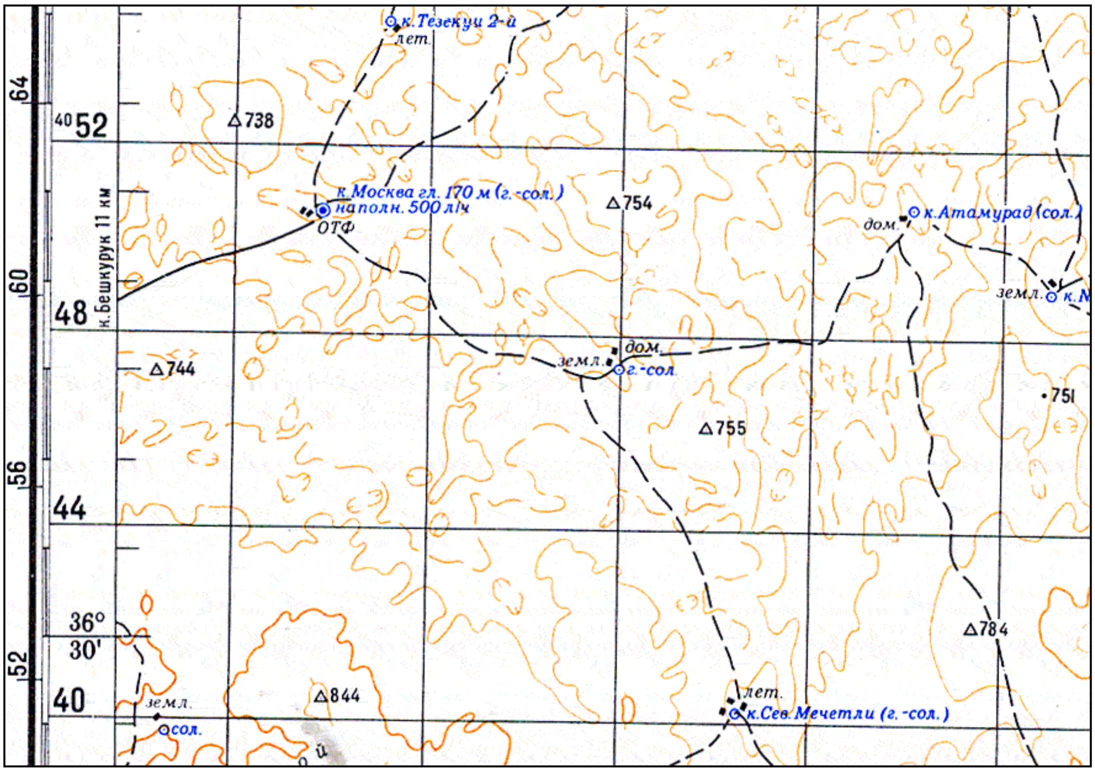
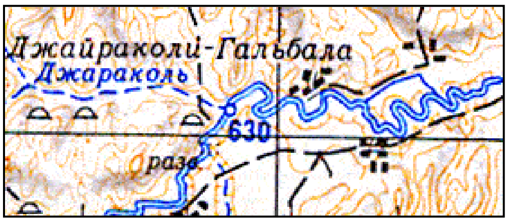


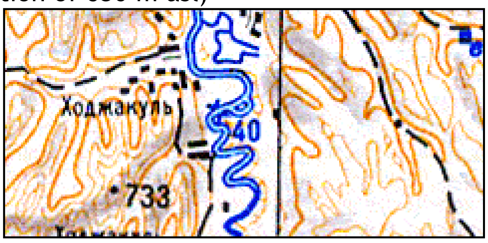
Figure 6.2. Extract of a Soviet 1:200,000 map showing several wells, and in particular, a well called Moscow Well (*колодец Москва*), which is 170 m deep and yields bitter-salty water at 500 L/hour.

Other features that may be observed include

вдхр. = водохранились = reservoir (in the context of northern Afghanistan, this probably represents a subterranean rainwater storage cistern).

Spot elevations on rivers are shown as open circles, with the elevation in m asl shown in blue (in the below left example, a spot elevation of 630 m asl)





The width of the river, in metres, is shown as a blue figure adjacent to two blue chevrons (in the above right example, the River Qaysar is 40 m wide at the indicated point):

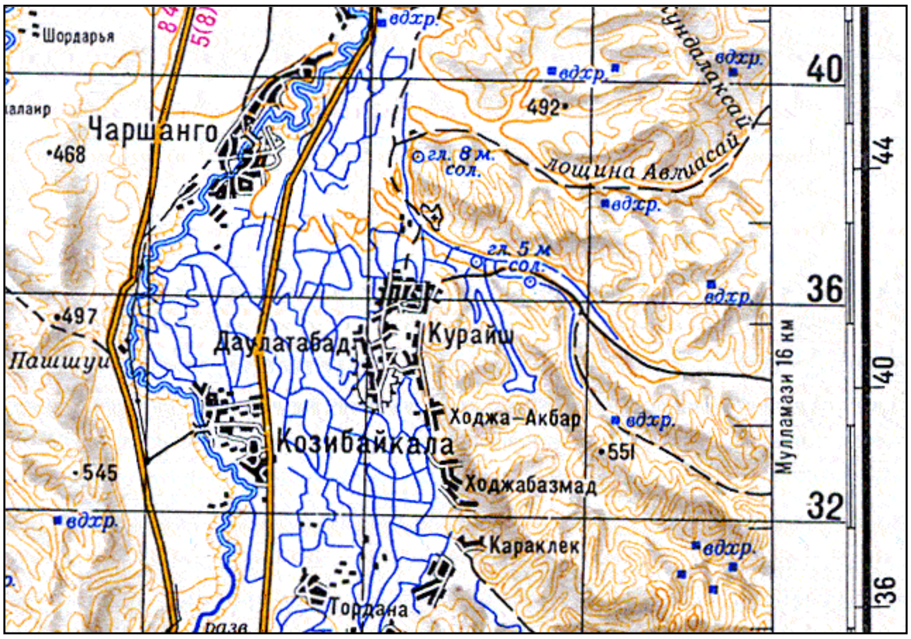


Figure 6.3. Extract of a Soviet 1:200,000 map of Dawlatabad showing several shallow saline wells, and a number of rainwater storage cisterns.

Note that geology and aquifers do not recognise national borders! By registering and assessing the occurrence of wells and groundwater in the areas of, say, Turkmenistan, bordering Faryab, it is possible to gain increased hydrogeological knowledge of the likely resources in Afghanistan. In the NORPLAN project, hydrogeological features were mapped on topographic maps some 40 km into Turkmen territory.

6.2 Mishkin's (1968) Hydrogeological Map

We have already encountered Mishkin's (1968) hydrogeological map of northern Afghanistan (Figure 2.1), and other similar documents are likely to exist for other regions of the country.

Again, in the NORPLAN mapping of Faryab, the relevant section of the map was examined. A bitmap was overlain in Google Earth for the purposes of georeferencing:

- The marked wells, springs and boreholes were geotagged in Google Earth and the information was abstracted to the standard format (Section 10).
- groundwater contours were digitised in Google Earth and stored as kml files for later conversion to GIS format.
- the polygons representing areas of varying salinity were digitised in Google Earth and stored as kml files for later conversion to GIS format.

A key to Mishkin's map is shown in Appendix B.

6.3 Hydrogeological Map of the Soviet Union

A hydrogeological map of the Soviet Union is available, accompanied by a multi-volume hydrogeological treatise. Each of the former Soviet republics adjoining Afghanistan has its own volume. For example, for Turkmenistan:

- **Крыжановский, В.А. (editor) (1972).** Гидрогеология СССР: том 38: Туркменская ССР. Институт Геологии Совета Министров Туркменской ССР. Издат. Недра, Москва. *Hydrogeology of the USSR. Vol. 38. Turkmenistan.* Nedra, Moscow. 565 pp.

The map itself is not dissimilar to that of Mishkin (1968); showing broad hydrogeological units and key wells and boreholes. On the map (Figure 6.4), boreholes are shown as black dots, with the figure to the left being a well index number and the figure to the right showing (in the

numerator) the static groundwater level (m bgl) and (in the denominator) the groundwater dry residue (or salinity, g/L).

Figure 6.4. The hydrogeological map of the Soviet Union, showing the area of Turkmenistan adjacent to Faryab Province.

The accompanying volume provides explanatory notes and tables of well logs and groundwater analyses (Appendix C).

7 Existing Sources of Point Data

NORPLAN envisage that a typical WebGIS hydrogeological provincial survey will be able to accommodate three main types of point data:

- Meteorological stations (MET)
- River / surface water stations / observations (SUR)
- Groundwater points (wells, boreholes, springs, karezes) (GRO)

Data of these types will typically be derived from both external existing databases and from field surveys carried out during the provincial mapping exercise. While surveying Faryab Province, we have also allowed for the entry of a fourth type of data, collected specifically as part of fieldwork in Faryab:

- Soil sampling / observation locations (SOL)

It is not necessarily envisaged that soil sample data will be collected as part of surveys of other Provinces.

The standard formats for data entry used for Faryab Province can be found in Section 10.

7.1 Meteorological Data

A number of sources of meteorological data can usually be located for each Province. In the case of Faryab, these are:

- The AGROMET meteorological stations, established by the US Geological Survey in conjunction with MAIL. Data have been obtained from the USGS Liaison officer, Agromet Project, Ministry Of Agriculture, Irrigation and Livestock (MAIL).
- The WMO international network of stations. Data available at the NOAA website: e.g. for Maimana at http://www.nws.noaa.gov/tg/siteloc.php or ftp://dossier.ogp.noaa.gov/GCOS/WMO-Normals/RA-II/AH/40922.TXT or http://geodata.lib.ncsu.edu/fedgov/noaa/clino/TABLES/REG_II/AH/ or at http://data.un.org
- Meteorological and snow monitoring stations operated by the Ministry of Energy and Water.

Additional data may also be available from the Ministry of Transport and Civil Aviation.

Basic information will be entered into the standard Excel data collection formats (Section 10). More complex data series (time-series, analyses) will be referenced by hyperlinks to additional files (usually pdf or xls format).

7.2 Surface Water Stations and Observations

Data and details of current river gauging stations can usually be obtained by application to

- Ministry of Energy and Water

Historic river gauging data is available from

- the US Geological Survey website at http://afghanistan.cr.usgs.gov/water .

Other organisations, such as DACAAR, may also hold information regarding "one-off" sampling or gauging.

Basic information will be entered into the standard Excel data collection formats (Section 10). More complex data series (time-series, analyses) will be referenced by hyperlinks to additional files (usually pdf or xls format).

7.3 Groundwater Data

For each province, an attempt should be made to approach all relevant organisations to obtain records and drilling logs of groundwater points, namely:

- wells,
- drilled boreholes (including mineral and hydrocarbons boreholes, if useful geological or hydrogeological data is associated with these).
- springs
- karezes.

Basic information will be entered into the standard Excel data collection formats (Section 10). More complex data series (time-series, analyses, drilling logs, geophysical logs) will be referenced by hyperlinks to additional files (usually pdf or xls format).

These organisations will typically include:

- Ministries, at both national and provincial level
  - MRRD
  - MoM / Afghan Geological Survey
  - MAIL
  - MoEW
  - MUDA / CAWSS / AUWSSC
- NGOs known to be operating in the fields of water supply or irrigation in the Province in question.
- UN organs, including UNICEF and possibly also UNHCR, FAO, UNDP, UNEP.
- Private drilling companies and consultancies
- Foreign and international donors, lending organs and consultancies.
- US Geological Survey (who provide geophysical logs and details of hydrocarbon exploration boreholes via their own WebGIS at http://afghanistan.cr.usgs.gov/flexviewer/).

The experience of NORPLAN in Faryab is that the main sources of hydrogeological information have been:

i) UNICEF (although only older reports)
ii) MRRD (relatively few, though good quality, borehole records)
iii) Norwegian Church Aid
iv) DACAAR

Of these, DACAAR hold by far the most comprehensive sets of data.

<u>DACAAR's datasets</u>

For Faryab, DACAAR possess several datasets of wells, boreholes and springs. There is significant overlap between the data sets and significant quality control may be required to attempt to remove / merge duplicate data:

- The main water-point (WSG) database, which is largely a management database, to keep track of water well and borehole infrastructure, location and maintenance. Contains data on location and construction of water points, but limited hydrogeological data.

- A separate database of drilled borehole logs, maintained in the environment of the Schlumberger software *Hydrogeoanalyst*. This software enables pdf representations of well construction, water level and geology to be generated.
- A separate database of groundwater analyses, maintained in the environment of the Schlumberger software *Aquachem*.
- For Faryab, an Excel file containing results of a rapid survey of groundwater electrical conductivity.
- Separate Excel files containing time series data on water level (and sometimes, electrical conductivity and temperature) for DACAAR's network of observation wells.

In addition, DACAAR have a comprehensive series of reports, which contain additional details of groundwater research and development projects, from which data can be abstracted.

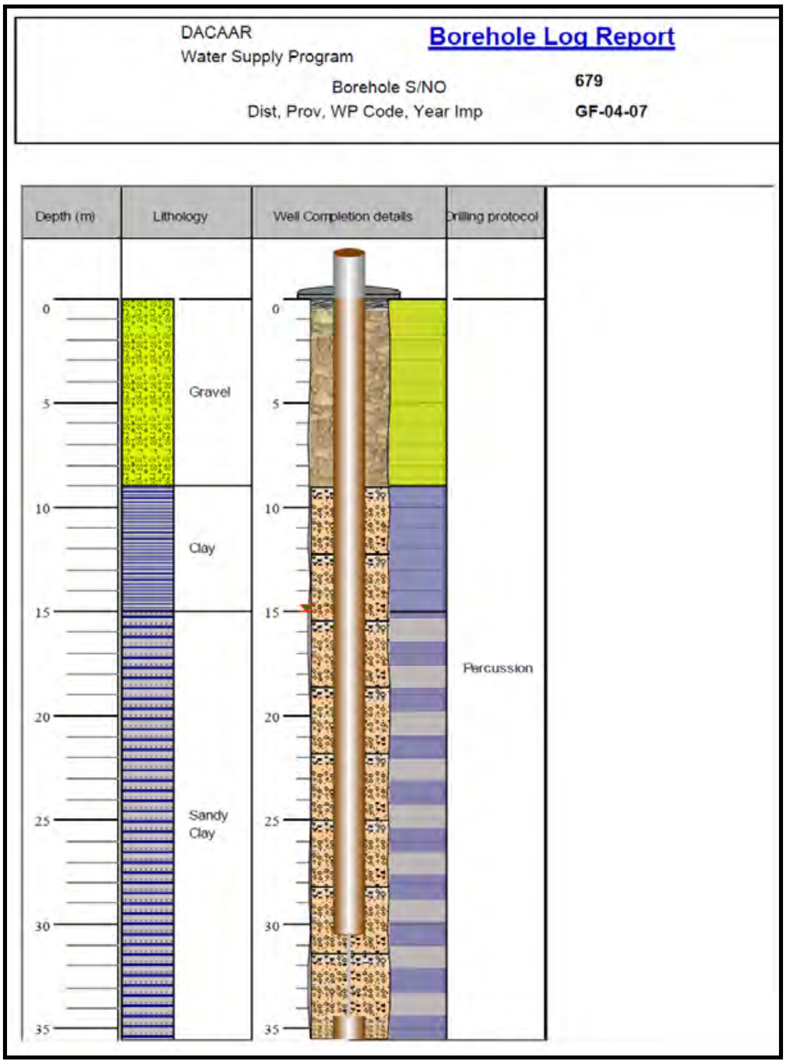


Figure 7.1. An example of a borehole log generated by DACAAR's *Hydrogeoanalyst* software. This one shows a well filter from 30.5 to 34.5 m bgl and a static water level of 15 m bgl.

8 Remote Sensing

It is not uncommon for NGOs and other organizations to be far more diligent at recording wells and boreholes than recording the occurrence of natural springs or karezes. These latter are often extremely important for understanding the natural hydrogeological regime of the area, however. Fortunately, these features can often be identified from remote sensing tools, of which by far the most readily available is Google Earth. Springs can often be identified in arid areas by verdant vegetation (Figure 8.1).

Figure 8.1. Four spring areas in Ghormach, identified from Google Earth. Once identified, coordinates (latitude and longitude) can be read directly.

Figure 8.2. A line of wells near Qalat, probably representing the line of a karez.

9 New Field Surveys

The main source of information for any Provincial Hydrogeological Survey will be **existing data, well logs and literature.**

There is no definitive recipe for how many data points are required to produce a good hydrogeological map. Indeed, a hydrogeological map will always be a “work in progress” to be amended and improved as new data become available. A Web-based mapping tool has the distinct advantage that it is not “set in stone”, but can be continuously modified and updated.

As a very rough guideline, however, we would suggest that a reasonably informative hydrogeological map of an Afghan Province can be based on:

(i) good basic geological and topographical maps

(ii) around 1000 or more groundwater points (wells, boreholes, springs) with basic information on water depth / salinity / geology etc.

(iii) upwards of one hundred reliable groundwater analyses

Even with less information than this, a meaningful map can be produced.

It may be decided, however, to supplement the existing data set with new data collected by means of field surveys.

The purpose of these surveys can be:

- To supplement the existing data set with registration of wells, boreholes, karezes and springs in districts or lithologies with sparse existing coverage. In this case, registration implies locating the groundwater feature “on the ground” with geographical coordinates and, if possible, collecting data on its rest water level, water quality and, if possible, water yield or discharge.
- To investigate specific hydrogeological issues, in order to elucidate, for example:
  - hydrogeological flow pathways,
  - groundwater chemical evolution,
  - recharge mechanisms and hence sustainable water resources,
  - the hydraulic properties of specific aquifers, especially those that are poorly represented by existing data.

To illustrate the need for and purpose of new field surveys, during the course of the hydrogeological mapping of Faryab, NORPLAN have proposed or carried out:

<u>Regional Surveys</u>

- Collection of samples of rainfall and snowfall during winter and early spring at three different locations in Faryab (Gurziwan, Maimana and Andkhoi). Such winter precipitation is believed to represent the main source of recharge to aquifers in Faryab, either directly (in the highlands) or via downstream river infiltration (in the lowlands). The samples were analysed chemically and isotopically for ^{18}O and ^{2}H, in the hope that chemical and isotopic signatures of precipitation could be traced along hydrological / recharge pathways via river water and, eventually, to groundwater. It was hoped that this would (a) clarify the degree to which precipitation is up-concentrated by evapotranspirative processes and (b) recharge mechanisms.
- Systematic surveys of the main river channels carrying potential recharge water from the highlands to the semi-desert lowlands. In the case of Faryab, these were the Maimana and Shirin Tagab rivers. The river surveys were carried out in late spring, towards the end of the snowmelt season. The rivers were systematically observed at regular intervals along their length, sampled for comprehensive

chemical analysis (to document any progressive salinisation) and for stable isotope analysis.

- A “rapid” supplementary registration of around 200 groundwater features (wells, boreholes, springs, karezes) in districts that were under-represented in existing data-sets: Kohistan, Qaysar, Gurziwan, Bilchiragh, northern districts around Andkhoi. Approximately 1 in 3 registered sources was sampled for comprehensive chemical analysis and 1 in 9 for stable isotope (^{18}O and ^{2}H) analysis.

- At selected sites, chosen in order to represent a variety of underlying lithologies and topographical settings, soil samples were taken at depths of 40 and 70 cm. These were extracted with deionised water at the laboratory, and the extracts were analysed for major cations and anions. This exercise was designed to document the presence of readily soluble salts residing or accumulating in soils, with the intention of clarifying the likelihood of direct recharge occurring regionally via soils. This exercise was undertaken specifically for Faryab Province and should not necessarily be regarded as obligatopry in other provinces.

<u>Specific Local Investigations</u>

Within Faryab, it was also proposed to expend the limited drilling resources available to the mapping project on three site-specific investigations.

- Drilling of one-two carefully documented deep boreholes in the Andkhoi area, to test the hypothesis that, at specific depths and specific locations (e.g. in the vicinity of irrigation channels), pockets of fresher groundwater may be present. Careful observation during drilling should also elucidate any vertical stratification of the groundwater.

- Drilling of a test pumping well in the alluvial corridor of the Shirin Tagab river, just south of Faizabad, surrounded by an array of nested piezometers / observation boreholes in the Quaternary and Neogene deposits. The specific objective of this study was to examine, by means of hydraulic analysis and chemical / isotopic sampling, the potential connectivity between the Shirin Tagab river and the groundwater system.

- Drilling of one or more test pumping well(s) and set of observation boreholes in the significant Quaternary sand / gravel aquifer to the west of Maimana Airport, in order to document the hydraulic properties of this aquifer unit and to assess the sustainability of any future abstraction, which will likely be dependent on its connectivity (or lack of it) with the Maimana River.

Had additional resources been available, other research tasks that could fruitfully have been undertaken might have included:

- Prospective drilling for fresher groundwater resources in northern Faryab along the course of what appears to be a palaeo-river channel stretching from the Shirin Tagab valley to the Kelif Uzboy of Turkmenistan. One would here have been testing the specific hypothesis that fresh groundwater resources might persist along such palaeo-river channels.

- Drilling at a limited number of localities into Neogene aquifer deposits, both outside and within the main river valleys. It is widely accepted by hydrogeologists that the Neogene aquifers have inferior hydraulic properties to the Quaternary alluvial aquifers and almost invariably contain saline water. There is, however, very little available documented borehole data to confirm this assumption. Recent data from Kabul does, indeed, suggest that Neogene sedimentary rocks can contain viable aquifer horizons at depth.

The methodologies for all these field surveys are documented in Part 2 of this report.

10 Data Standardisation and Quality Control

In the NORPLAN hydrogeological mapping concept, all point source data (whether derived from existing data, literature searches or field surveys) has been entered into one of four standard Excel reporting formats:

- GRO_filename_QA.xls or xlsx for groundwater points (wells, karezes, springs, boreholes)
- SUR_filename_QA.xls or xlsx for surface water observation / sample points or gauging stations
- MET_filename_QA.xls or xlsx for meteorological stations, observations or precipitation sampling points
- SOL_filename_QA.xls or xlsx for soil observation or sampling points

The QA suffix is only added to files that have undergone quality assurance (see below).

Each Excel file should contain at least two worksheets:

- a "Data" sheet should contain the standard table, with columns representing different fields of information and rows representing different geographical points
- a "File History" sheet, containing metadata about where the data has been derived from and how (and by whom) it has been processed (Figure 10.2).

Complex data, such as:

- diagrams showing geological columns, well construction, geophysical logs
- water analyses
- test pumping results
- long time-series of monitoring data

are not accommodated directly into the spreadsheet. Rather, the pdf, jpg or xls files containing such data are referenced from the spreadsheet by means of hyperlinks to the file location. In a WebGIS environment, it is envisaged that these hyperlinks can be activated by clicking on the point in question.

The following pages contain the specifications for each individual file format. In each table, each field name represents a single column in an Excel spreadsheet. Each location / record is entered in a single row. For fields marked in green, a table of multiple values (e.g. water levels on various dates) can be entered for a single record.

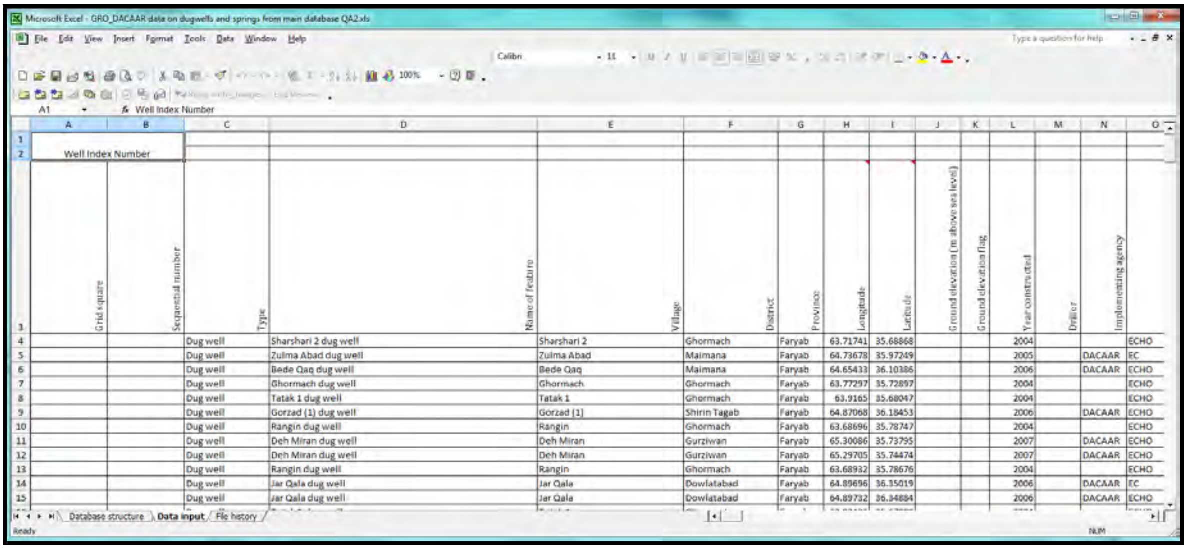


Figure 10.1. Example of well / spring data in an Excel spreadsheet.

Table 10.1. Excel data field format for groundwater data points.

	GRO Groundwater points		
	Field Names	**Notes**	**Permitted values**
	Grid square	NOTE: This is, effectively the station ID	
	Sequential number		
	Type	Data validation: limited number of values permitted	Unknown groundwater, Dug well, Drilled borehole, Spring, Karez
	Name of feature	*Text*	
	Village	*Text*	
	District	Data validation: limited number of values permitted	Almar, Andkhoi, Bilchiragh, Dowlatabad, Ghormach, Gurziwan, Khani Chahar Bagh, Khwaja Sabz Posh, Kohistan, Maimana, Pashtun Kot, Qaysar, Qaramqol, Qurgan, Shirin Tagab
	Province	Data validation: limited number of values permitted	Faryab, Jawzjan, Sar-e-Pol, Balkh, Badghis, Turkmenistan
	Longitude	*Decimal degrees*	*For karezes, enter location of karez mouth*
	Latitude	*Decimal degrees*	*For karezes, enter location of karez mouth*
	Ground elevation (m above sea level)	*Number (real)*	
	Ground elevation flag	Data validation: limited number of values permitted (Not known = default)	GPS, Surveyed on site, Estimated from digital terrain model, Estimated from map, Not known
	Year constructed	*Year (integer)*	
	Driller	*Text*	
	Implementing agency	*Text*	
	Donor	*Text*	
	Data supplied by	*Text*	
	Use	Data validation: limited number of values permitted	Public supply, Private supply, School, Health Centre, Industry, Irrigation, Multiple use, Observation, Exploration, Hydrocarbon, Disused, Other
	Pump	*Text*	
	Aquifer	*Text*	
	Geological / construction log scanned	Data validation: limited number of values permitted (None = Default)	Geological log, Construction log, Combined log, None
	Link to geological/construction log	Contains hyperlink(s) to pdf (or other file) of geological/construction log(s)	
	Depth to base of Quaternary (m)	*Number (real)*	
	Depth to base of Neogene (m)	*Number (real)*	
	Geophysical log scanned	Data validation: limited number of values permitted (No = Default)	Yes, No
	Link to geophysical log	Contains hyperlink(s) to pdf (or other file) of geophysical log(s)	
	Well depth (m)	*Number (real)*	
	Completed diameter at top (mm)	*Number (real)*	
	Completed diameter at bottom (mm)	*Number (real)*	
	Water quality analysis available	Data validation: limited number of values permitted (No = Default)	Yes, No
	Link to water quality analysis	Contains Analysis ID and hyperlink to file with water analysis data	
	Date: *Date*	There needs to be the possibility for multiple entries under these fields (i.e. electrical conductivity data for a series of dates)	
	Electrical conductivity (μS/cm): *Number (real)*		
	Laboratory (L) or Field (F)		Laboratory, Field, Unknown, Estimated from TDS
	Corrected to (°C): *Number (real)*		
	Problematic water quality components	*Text*	
	Lining type	There needs to be the possibility for multiple entries under these fields (i.e. a number of different types of lining at different depths)	Plain casing, Filter, Plain and filter, Open hole, Concrete rings, Masonry, Brick, Other dug well lining
	From (m bwt): *Number (real)*		
	To (m bwt): *Number (real)*		
	Diameter (mm): *Number (real)*		
	Material		PVC, Steel, Galvanised steel, None (open hole), Stone/brick, Concrete
	Date: *Date*	There needs to be the possibility for multiple entries under these fields (i.e. water levels for a series of dates)	
	Static water level (m): *Number (real)*		
	Unit		Artesian (but level not quantified), m above ground level (artesian), m below ground level, m below well top, m above sea level, m above well base, m above

			well base (presumed)
	Additional water level data available	Data validation: limited number of values permitted (No = Default)	Yes, No
	Link to file containing water level data	Contains hyperlink to file with additional water level data	
	Maximum operational yield (L/s)	*Number (real)*	
	Date: *Date*	There needs to be the possibility for multiple entries under these fields (i.e. yield / drawdown data for a series of dates)	
	Yield (L/s): *Number (real)*		
	Drawdown (m): *Number (real)*		
	Duration (hr): *Number (real)*		
	Additional pumping test data available	Data validation: limited number of values permitted (No = Default)	Yes, No
	Link to file containing pumping test data	Contains hyperlink to file with additional pumping test data	
	Date: *Date*	There needs to be the possibility for multiple entries under these fields (i.e. flow data for a series of dates)	
	Flow or discharge (L/s): *number (real)*		
	Estimated or gauged		Estimated, Gauged, Not known
	Comments and additional information (e.g. Make of pump)	*Text*	

Key:

	= provision to be made for multiple entries under these field (i.e. table associated with each row)
	= data validation. Only a limited number of values permitted
	= hyperlink to pdf, xls or jpg (or other) file

	= these fields apply to wells and boreholes only
	= these fields apply to springs and karezes only

Table 10.2. Excel data field format for surface water stations and observation points.

SUR: Surface water data		
Field Names	**Notes**	**Permitted values**
Grid square	NOTE: This is, effectively the station ID	
Sequential number		
Type	Data validation: limited number of values permitted	Permanent station, Spot gauging, spot sampling, Spot gauging and sampling, Observation
Name of feature	*Text*	
Name of River	*Text*	
District	Data validation: limited number of values permitted	Almar, Andkhoi, Bilchiragh, Dowlatabad, Ghormach, Gurziwan, Khani Chahar Bagh, Khwaja Sabz Posh, Kohistan, Maimana, Pashtun Kot, Qaysar, Qaramqol, Qurgan, Shirin Tagab
Province	Data validation: limited number of values permitted	Faryab, Jawzjan, Sar-e-Pol, Balkh, Badghis, Kunduz, Turkmenistan
Longitude	*Decimal degrees*	
Latitude	*Decimal degrees*	
Year data commence	*Year (integer)*	
Year data cease	*Year (integer)*	
Agency responsible	*Text*	
Data supplied by	*Text*	
Elevation of station (general) (m asl)	*Number (real)*	
Elevation (general) data flag	Data validation: limited number of values permitted (default = Unknown)	GPS, Surveyed on site, Estimated from digital terrain model, Estimated from map, Unknown
Date of water level measurement: *Date*	There needs to be the possibility for multiple entries under these fields (i.e. water level data for a series of dates)	
Water level (m above sea level): *Number (real)*		
Method: *Text*		
Typical dry season flow (m3/s)	*Number (real)*	
Typical wet season / snowmelt flow (m3/s)	*Number (real)*	
Typical annual average flow (m3/s)	*Number (real)*	
Date of flow gauging: *Date*	There needs to be the possibility for multiple entries under these fields (i.e. flow gauging data for a series of dates)	
Flow measurement (m3/s): *Number (real)*		
Method: *Text*		
Additional water level / flow data available	Data validation: limited number of values permitted (default = No)	Yes, No
Link to additional water level / flow data	Contains hyperlink(s) to xls (or other file) of water level / flow data	
Date: *Date*	There needs to be the possibility for multiple entries under these fields (e.g. electrical conductivity data for a series of dates)	
Temperature (°C): *Number (real)*		
Electrical conductivity (µS/cm): *Number (real)*		
Laboratory (L) or Field (F)		Laboratory, Field, Unknown
Corrected to (°C): *Number (real)*		
Date: *Date*	There needs to be the possibility for multiple entries under these fields (i.e. pH data for a series of dates)	
pH: *Number (real)*		
Laboratory (L) or Field (F)		Laboratory, Field, Unknown
Additional water quality data available	Data validation: limited number of values permitted (default = No)	Yes, No
Link to additional water quality data	Contains hyperlink(s) to xls (or other file) of water quality data	
Problematic water quality components	*Text*	
Comments and additional information	*Text*	

Table 10.3. Excel data field format for meteorological stations and observation points.

MET: Meteorological data		
Field Names	**Notes**	**Permitted values**
Grid square	NOTE: This is, effectively the station ID	
Sequential number		
Type	Data validation: limited number of values permitted	Permanent station, Spot measurements, Spot chemistry
Name of feature	*Text*	
District	Data validation: limited number of values permitted	Almar, Andkhoi, Bilchiragh, Dowlatabad, Ghormach, Gurziwan, Khani Chahar Bagh, Khwaja Sabz Posh, Kohistan, Maimana, Pashtun Kot, Qaysar, Qaramqol, Qurgan, Shirin Tagab
Province	Data validation: limited number of values permitted	Faryab, Jawzjan, Sar-e-Pol, Balkh, Badghis, Kunduz, Turkmenistan
Longitude	*Decimal degrees*	
Latitude	*Decimal degrees*	
Year data commence	*Year (integer)*	
Year data cease	*Year (integer)*	
Agency responsible	*Text*	
Data supplied by	*Text*	
Elevation (general) (m asl)	*Number (real)*	
Elevation (general) data flag	Data validation: limited number of values permitted (default = Unknown)	GPS, Surveyed on site, Estimated from digital terrain model, Estimated from map, Unknown
Annual average precipitation (mm)	*Number (real)*	
Period (for precipitation average)	*Text*	
Annual average air temperature (°C)	*Number (real)*	
Period (for air temperature average)	*Text*	
Additional precipitation data available	Data validation: limited number of values permitted (default = No)	Yes, No
Link to additional precipitation data	Contains hyperlink(s) to xls (or other file) of water level / flow data	
Additional evapotranspiration data available	Data validation: limited number of values permitted (default = No)	Yes, No
Link to additional evapotranspiration data	Contains hyperlink(s) to xls (or other file) of water level / flow data	
Additional temperature data available	Data validation: limited number of values permitted (default = No)	Yes, No
Link to additional temperature data	Contains hyperlink(s) to xls (or other file) of water level / flow data	
Additional chemistry / isotope data available	Data validation: limited number of values permitted (default = No)	Yes, No
Link to additional chemistry / isotope data	Contains hyperlink(s) to xls (or other file) of water level / flow data	
Additional other data available	Data validation: limited number of values permitted (default = No)	Yes, No
Type of other data	*Text*	
Link to additional other data	Contains hyperlink(s) to xls (or other file) of water level / flow data	
Comments and additional information	*Text*	

Table 10.4. Excel data field format for soil sampling and observation points.

SOL: Soil data		
Field Names	**Notes**	**Permitted values**
Grid square	NOTE: This is, effectively the station ID	
Sequential number		
Type	Data validation: limited number of values permitted	Soil sampling, Observation only
Location / village	*Text*	
District	Data validation: limited number of values permitted	Almar, Andkhoi, Bilchiragh, Dowlatabad, Ghormach, Gurziwan, Khani Chahar Bagh, Khwaja Sabz Posh, Kohistan, Maimana, Pashtun Kot, Qaysar, Qaramqol, Qurgan, Shirin Tagab
Province	Data validation: limited number of values permitted	Faryab, Jawzjan, Sar-e-Pol, Balkh, Badghis, Kunduz, Turkmenistan
Longitude	*Decimal degrees*	
Latitude	*Decimal degrees*	
Date of sample / observation	*Date*	
Agency responsible	*Text*	
Data supplied by	*Text*	
Elevation (general) (m asl)	*Number (real)*	
Elevation (general) data flag	Data validation: limited number of values permitted (default = Unknown)	GPS, Surveyed on site, Estimated from digital terrain model, Estimated from map, Unknown
Underlying geology (code from 1:250,000 USGS/AGS maps)	*Text*	
Depth range (cm): *Text*	There needs to be the possibility for multiple entries under these fields (i.e. descriptions at various depths)	
Soil description: *Text*		
Soil samples taken	Data validation: limited number of values permitted (default = No)	Yes, No
Sample depth (cm): *Number (integer)*	There needs to be the possibility for multiple entries under these fields (i.e. samples at various depths)	
Sample number: *Text*		
Soil chemical analysis data available	Data validation: limited number of values permitted (default = No)	Yes, No
Link to soil chemical analysis	Analysis number and hyperlink(s) to xls (or other file) of analytical data	
Grain size analysis data available	Data validation: limited number of values permitted (default = No)	Yes, No
Link to soil grain size analysis	Analysis number and hyperlink(s) to xls (or other file) of analytical data	
Other data or photos available	Data validation: limited number of values permitted (default = No)	Yes, No
Link to other data	Analysis number and hyperlink(s) to pdf (or other file) of photos / data	
Comments and additional information	*Text*	

FILE HISTORY

This file was compiled from the spreadsheet Almar District.xls, sent by DACAAR to David Banks, via Naqibullah Abrar in October 2012. The data and well logs were all prepared from DACAAR's Hydrogeoanalyst program, as of October 2012.

This file compiled by DB 12/10/12 and slightly modified 15/1/13

When compared with pdf versions of well logs supplied with DACAAR, two discrepancies were noted. These were:

Incorrect logs identified for wells ALF-15-08 and ALF-16-08 were noted
Remedy: Correct logs for ALF-15-08 and ALF-16-08 were obtained from Eng. Jaweed, DACAAR February 2013, and Depth of AF-15-08 corrected to 50 m on 23/3/13 (also on Google Earth)
File re-saved in QA2 format on 23/3/13 by D Banks NORPLAN

Figure 10.2. Example of a file history text box, saved on the “File History” worksheet of each data workbook.

10.1 Well Index Number

It is highly beneficial to assign each groundwater record (well, borehole, spring or karez) a unique identifier.

It is helpful if this identifier contains some information regarding the geographic location of the feature.

It is unwise to use Province or District names in the identifier, as these political units will inevitably subject to change and reorganisation.

One suggestion has been to subdivide Afghanistan into grid squares based on latitude and longitude, at 15 minute intervals. Each grid square will be designated by an eight character reference, referring to the coordinates at the bottom left of the grid square:

For example, the grid square bounded by longitude 65°15’ and 65°30’ and latitude 36°30’ and 36°45’, would be designated square 65153630. Within each grid square, we would number groundwater features sequentially. Thus, the first borehole to be registered within the above grid square would be designated 65153630_0001.

10.2 Data Quality Control

Data will be derived from many differing organisations. Those who have collected the data will have very differing competencies regarding use of GPS handsets and maps, and familiarity with citing coordinates.

Data quality control will normally be undertaken when the data are transferred from their original format (which may be paper reports, pdf files or existing Excel or Access database files). This job should be done by a hydrogeologist, who can apply “common sense” checks to several fields.

Our experience from Faryab suggests that a reasonable, and not unduly onerous, system of quality control should incorporate the following elements.

1) Is it clear how the coordinates are cited in the original data source? They may be cited as degrees;minutes;seconds, degrees;decimal minutes or decimal degrees. For data entry, all coordinates should be converted to decimal degrees.
2) Do the coordinates make sense? Do they fall within the Province and District indicated (be aware that district boundaries may have shifted with time, when considering historical records)? Do they fall in inhabited areas (where one would expect wells and boreholes) or in uninhabited desert? An easy way of checking all

these things is to import the records to Google Earth, where they can be viewed with ease. A quick and easy import tool is the ***MapExcelData.xls*** macro by Process Trends, which converts Excel columns to kml files. This tool is currently available at http://processtrends.com/pg_google_earth.htm#Making KML Files with Excel VBA.

Experience from Faryab indicates that GPS positioning is not necessarily a highly accurate means of locating wells on digital maps in the field. This may be due to several factors:

- GPS factors; lack of available satellites, or operator inexperience in not waiting for adequate satellite acquisition.
- Just plausibly, military interference with GPS accuracy.
- Lack of accuracy in available digital base-maps, such as Google Earth (such that, while a GPS reading may be accurate, it does not correspond to the digital underlay)

Our experience suggests that the degree of correspondence between a field-derived GPS coordinate and Google Earth is probably not better than ± 100 m. In an area of high, varied topography, this can lead to significant errors in estimating elevation.

3) If the original record cites an elevation, is it in feet or metres above sea level? Does it make sense? You can check this on existing topographic maps or (roughly) in Google Earth. Bear in mind that, in very hilly or mountainous terrain, the digital elevation model in Google Earth may not have adequate resolution to give you a good elevation.

4) Does well depth make sense? Is it in metres or feet? Boreholes for water supply in Afghanistan are seldom more than 200 m deep (though, sometimes, they can be!) and dug wells don't exceed several tens of metres.

5) How is the static water level cited? It is usually in metres below ground level (occasionally metres below well top - these will usually be very similar). Very occasionally, the water level may be cited as an absolute elevation (metres above sea level) or as metres above the well base (depth of water column in well). Choose the right "flag" for this in the Excel spreadsheet and convert if necessary. The flags available are:

    - Artesian (but not quantified)
    - m above ground level (artesian)
    - m below ground level,
    - m below well top,
    - m above sea level,
    - m above well base,
    - m above well base (presumed) *(used in cases where the water level appears to be m above well base, but it is not clear if this is the case)*

6) Does the well construction make sense? Are the lengths of well filter below the static water level (this is usually, though not always, the case, if the well has been correctly constructed)?

7) Does the electrical conductivity make sense? Fresh groundwater usually has a conductivity of several hundred to, say 1500 µS/cm. Saline groundwater can have a conductivity of many thousands of 1500 µS/cm.

8) Does any well log or construction diagram tally with digital data that are supplied in a database or Excel spreadsheet? Check them against each other.

9) If data has been supplied by DACAAR from their WSG database, from *Hydrogeoanalyst* and from *Aquachem*, it is possible that one and the same borehole may be registered in all three databases. Try to identify and merge duplicate

records, if possible (this can be done by sorting wells according to latitude and longitude in Excel). If it is not possible to identify two records as duplicates with certainty, it is usually best to retain both records.

10) Use the “Comments” field to add a description of the well, especially capturing any data that does not fit well into the other specified fields. The “CONCATENATE” function in Excel can be useful in generating comments fields.

11 Data Presentation

The final product of the Provincial hydrogeological mapping has already been discussed in Section 2. In the NORPLAN concept, we envisage three fundamental hydrogeological mapping products being made available:

11.1 WebGIS

For users with access to the Internet, a large proportion of the information base can be made available via a WebGIS tool (see Section 2), incorporating

(i) basic mapping data (topography, geology),

(ii) access to raw data on wells, boreholes, springs etc. (which can be accessed by clicking on the point in question)

(iii) a limited number of interpretative layers:

- hydrogeological interpretation of geological map: outcrops of productive and less productive aquifers, aquitards etc.
- areas of saline water (or other poor water quality parameters)
- maps indicating depth to water table / piezometric surface

As a guide, the following structure has been proposed for the data layers to be made available via the menu of a WebGIS for Faryab Province.

Text Box 11.1. Proposed structure of hydrogeological WebGIS for Faryab Province

BLACK BOLD indicates primary menu options

Red Bold indicates secondary menu options

Green indicates tertiary menu options

Proposed Background Layers

GEOLOGICAL MAP

Geological units (click on polygon to identify, with description)

Geological contacts

Faults

Dykes

Hydrogeological units (click on polygon to identify, with description) (to be based on USGS naps, but reclassified by the hydrogeological team: cannot be selected at same time as geological units)

Mineral deposits (click to identify)

Contours on top of Ghory Formation (m asl):

Contours on top of Qezeltash Formation (m asl): These contours can be viewed at http://mapdss2.er.usgs.gov/openview/reports/Kunduz-Celestite-AOI-Reports/Petroleum%20GIS/Readme.html or at http://certmapper.cr.usgs.gov/data/envision/index.html?widgets=geologymaps&mapservice=geology_afghanistan&xmin=59.36&xmax=75.36&ymin=27.83&ymax=39.78

SOVIET 1968 HYDROGEOLOGICAL MAP

Salinity of groundwater (polygons, click to identify)

Groundwater elevation contours (click to identify)

TOPOGRAPHY

100 m contours (click to identify)

Digital elevation model (hover or click to identify elevation)

HYDROGRAPHY

Rivers

Lakes and reservoirs

Salt flats

METEOROLOGY

0.5 x 0.5° grid squares showing annual precipitation (click to obtain Excel data file)

0.5 x 0.5° grid squares showing annual average air temperature (click to obtain Excel data file)

POLITICAL and GEOGRAPHICAL

National (click on polygon to identify)

Provinces (click on polygon to identify)

Districts (click on polygon to identify)

District centres (click to identify)

Other towns and villages (click to identify) - keep this limited

Main roads

OTHER BASE MAPS

One could include satellite images or street maps. **BUT KEEP IT SIMPLE**

Proposed Point Data (If the point is clicked on, a screen summarising the basic data appears, with the option to download a table or pdf of the full well record)

In all menus below, boreholes where "Type" = "Hydrocarbon" are excluded, except in the case where the menu items "Hydrocarbon wells" or "geophysical log" are selected

GROUNDWATER POINTS (based on the "Type" field)

All

Dug wells

Drilled boreholes

Springs

Karezes

GROUNDWATER SALINITY (based on the electrical conductivity column)

All wells/boreholes/springs/karezes/unknown groundwater with EC info)

0-500 µS/cm

500-1000 µS/cm

1000-1500 µS/cm

1500 - 2000 µS/cm (colours of symbols increase through blue-green

2000 - 3000 µS/cm -yellow-orange-red) as EC increases)

3000 - 5000 µS/cm

5000 - 10000 µS/cm

>10000 µS/cm

WELLS WITH GROUNDWATER LEVEL DATA (based on the static water level column)

All wells / boreholes / unknown groundwater with water level data

Groundwater level 0-10 m below ground level

Groundwater level 10-20 m bgl

Groundwater level 20-30 m bgl

Groundwater level 30-40 m bgl

Groundwater level 40-50 m bgl

Groundwater level 50-75 m bgl

Groundwater level >75 m bgl

(symbols increase in colour from pale blue to deep blue as depth increases)

WELLS WITH DEPTH DATA (based on the well depth column)

All wells / boreholes / unknown groundwater with depth data

Depth = 0-10 m

Depth = 10-20 m

Depth = 20-30 m

Depth = 30-40 m

Depth = 40-60 m

Depth = 60-80 m

Depth = 80-100 m

Depth = 100-120 m

Depth = 120-150 m

Depth = 150-200 m

Depth = >200 m

(Symbols to be colour coded according to depth)

SPECIFIC WELL TYPES

Monitoring wells (all wells and boreholes where Use = observation)

Features marked on 1968 Soviet Hydrogeological map (all features from GRO_Wells and springs from 1968 Soviet Hydrogeological Map QA2.xls)

Wells and boreholes with logs

Construction / geological log

Geophysical log

Features with water analyses (if "Water quality analysis available = "Yes"

Features with additional water level data (if "Additional water level data = "Yes")

Wells with yield information (all features where a figure is entered under "Maximum operational yield" or "Yield")

Features with additional pumping test data (if "Additional pumping test data = "Yes")

Springs and karezes with flow information (all features with data under "Flow")

Hydrocarbon wells (all wells where Type = Hydrocarbon)

SURFACE WATER DATA POINTS (Points in "SUR" files)

All

Points with flow data

Points with water level data

Points with salinity / electrical conductivity data

Points with water analyses

METEOROLOGICAL STATIONS (points in "MET" files)

Stations with climate data

Stations with water quality analyses

SOIL SAMPLING LOCATIONS (points in "SOL" files)

All

11.2 Interpretative Maps

For users without ready access to the Internet, A2-A3 printouts or published versions of selected map views should be provided, including the distribution of wells, springs and boreholes and the three interpretative maps listed under 11.1 (iii) above:

- hydrogeological interpretation of geological map: outcrops of good and less good aquifers, aquitards etc.
- areas of saline water (or other poor water quality parameters)
- maps indicating depth to water table / piezometric surface

These should ideally be supplemented by hydrogeological cross-sections.

The **hydrogeological interpretation** of the geological map has already been discussed in Sections 2 and 4.5. The re-classification of geological units into hydrogeological units is best done in a workshop environment, involving senior hydrogeologists with field experience from the Province in question. The experience of these specialists in well drilling will often be adequate to classify aquifer units according to the International Association of Hydrogeologists' scheme (Appendix A). This experience should be backed up by (and

consistent with) real data from pumping tests or yield-drawdown tests. One might ask - what is the baseline for the definition of a "highly productive" or "moderately productive" aquifer? We would suggest that the workshop of hydrogeologists takes as its starting point the outline Hydrogeological Map of Asia, at http://unesdoc.unesco.org/images/0022/002207/220768EO.pdf

- China Geological Survey (2012). *Groundwater Serial Maps of China: Hydrogeological Map, Groundwater Resources Map, Geothermal Map - Explanation*. Sinomaps Press, ISBN 978-7-5031-7398-1.

The **areas of saline groundwater** can be delineated on the basis of real observations of electrical conductivity or total dissolved solids (TDS), collated during the field survey or data collection phases of the study. Agreement will need to be reached on what is defined as "fresh", "saline" or "brackish" water, and whether this definition can be founded in Afghan drinking water standards, or whether it is more sensible to use irrigation water standards. The WHO provides no standard for salinity in drinking water. It merely comments that water becomes increasingly unpalatable at TDS > 1000 mg/L. According to DACAAR, the UNICEF Water and Sanitation Group (WSG) in Afghanistan has assumed that water with TDS > 2000 mg/L or EC > 3000 µS/cm can be regarded as unacceptably saline.

Note that, according to Misstear et al. (2006), electrical conductivity can be converted to TDS by the relation:

TDS (mg/L) ≈ EC (µS/cm) x F

where F = 0.55 for sodium chloride-dominated waters

F = 0.75 for calcium bicarbonate-dominated waters

and F = 0.64 is often used where the water type is not clearly known

- **Misstear, B., Banks, D. & Clark, L. (2006).** Water Wells and Boreholes. Wiley, Chichester, 514 pp. ISBN/ISSN: 978-0-470-84989-7

If (and only if) adequate *and reliable* hydrochemical information is available, it may also be possible to delineate areas where there is a risk of drinking water standards being exceeded for individual elements such as arsenic or fluoride. Extreme caution should be exercised in presenting such maps, however, as a sparse data basis or unreliable analytical data can result dissemination of incorrect (and hazardous) information about groundwater quality.

As regards **maps of water table or piezometric surface**, we have already seen (Section 2) that it is common practice to represent the water table as a contoured surface in units of absolute elevation (m above sea level). Mishkin (1968) - Figure 2.1 - has already attempted this for northern Afghanistan, although at a rather "overview" scale and based on sparse (though probably very reliable) data.

In the context of this hydrogeological mapping concept, we recognise that the reduction of a "depth to water" measured in a well, to an "absolute water level elevation" is highly problematic, because we seldom have accurate data on ground level for many wells and boreholes, especially in areas of high topography. This is because (i) GPS units are rather poor at yielding highly accurate elevation estimates, (ii) available topographic maps lack resolution and (iii) the digital terrain models available, for example, at USGS websites or in Google Earth lack both resolution and lateral accuracy. Thus, we would recommend, as a first step, attempting to prepare maps of "depth to water table" in areas and aquifer units which are topographically relatively flat (river valleys, plains) and where there is an adequate data density. These can be shaded in different colours (e.g. "depths of blue") according to the depth to water table.

It is worth bearing in mind that total depths of dug wells can act as a proxy for depth to water table, as (for obvious reasons) wells are seldom dug manually to depths of more than a few metres below water table.

If success is achieved in preparing a "depth to groundwater" or "depth to water table" map, and if it is possible to make a reasonably accurate estimate of ground surface elevation, one can then attempt to produce maps of absolute elevation of the static

groundwater level, which may be useful in elucidating groundwater flow directions and gradients.

In complex multilayer aquifer systems and in areas of high topography, one must recognise that the concept of a single “groundwater level” may fail. Indeed, different groundwater heads may be encountered in different aquifer layers and, even in a single aquifer layer, groundwater level may change with depth. A sign that this may be the case is the measurement of different groundwater levels in shallow dug wells and deeper boreholes. In such cases it may not be possible to meaningfully construct a groundwater level map.

11.3 Hydrogeological Atlas

An illustrated report or short book should be prepared as a hard copy and pdf file, “talking” the reader through a conceptual hydrogeological model of the Province. Indeed, such a report, taken together with the maps in (11.2) could be described as a Hydrogeological Atlas of the province. The structure of the Atlas would cover:

- the history and culture of water resources in the Province.
- basic information of the location, topography and climate of the Province.
- the surface water hydrology of the Province.
- the geology of the Province and recent Neogene and Quaternary evolution.
- the hydrogeology of the Province: how the various units behave as aquifers or aquitards.
- a discussion of groundwater usage in the Province; the distribution of wells, springs, boreholes and karezes.
- a discussion of well yields and aquifer hydraulic properties. Information on the distribution of well yields. Where drawdown data are also available, Logan’s Approximation (or more sophisticated analysis techniques) can be applied to estimate aquifer hydraulic parameters.
- a brief consideration of individual districts or river basins in the Province, discussing the specific hydrogeological nature and groundwater resources of each area.
- a discussion of the likely regional groundwater evolution model, highlighting likely areas of recharge and discharge and considering the relative potential for direct and indirect recharge.
- a brief consideration of groundwater temperature distribution.
- a conceptualisation of the hydrogeochemical evolutionary pathways in the various catchments of the Province. Possibly commencing with a discussion of precipitation chemistry, soil / aquifer geochemistry, evapotranspirative up-concentration, groundwater mineralization, groundwater facies (water types). Presentation of hydrochemical maps.
- consideration of individual hydrochemical components, accompanied with maps.
- consideration of isotopic data and what light this may shed on the recharge pathways for aquifers.
- an overall resources assessment. Quantitative to the degree that available information permits.
- a consideration of limitations and opportunities for groundwater development in the Province. Future challenges and opportunities.

The above should not be regarded as a rigid template, but rather a suggestion for an Atlas structure.

When considering data that are sparse or which are not representatively geographically distributed (e.g. reliable groundwater quality analyses, well yield data, hydraulic properties data for aquifers), or where considering non-homogeneous aquifer systems (especially fractured aquifers) we would recommend that serious consideration be given to the use of Non-Parametric Exploratory Data Analysis as a tool for statistical analysis and mapping. This is dealt with in several publications, including:

- **Banks, D., Morland, G. & Frengstad, B. (2005).** Use of non-parametric statistics as a tool for the hydraulic and hydrogeochemical characterization of hard rock aquifers. **Scottish Journal of Geology**, 41(1), 69-79.
- **Reimann, C., Filzmoser, P., Garrett, R., Dutter, R. (2008).** *Statistical Data Analysis Explained: Applied Environmental Statistics with R.* Wiley, 362 pp.

and examples of this style of analysis are found in

- **Banks, D., Frengstad, B., Midtgård, Aa.K., Krog, J.R. & Strand, T. (1998).** The Chemistry of Norwegian Groundwaters: I. The distribution of radon, major and minor elements in 1604 crystalline bedrock groundwaters. **The Science of the Total Environment**, 222, 71-91.
- **Frengstad, B., Midtgård Skrede, Aa.K., Banks, D., Krog, J.R. & Siewers, U. (2000).** The chemistry of Norwegian groundwaters. III. The distribution of trace elements in 476 crystalline bedrock groundwaters, as analysed by ICP-MS techniques. **The Science of the Total Environment**, 246, 21-40.
- **Banks, D., Sæther, O.M., Ryghaug, P. & Reimann, C. (2001).** Hydrochemical distribution patterns in stream waters, Trøndelag, Central Norway. **The Science of the Total Environment** , 267, 1-21.
- **Frengstad, B., Banks, D. & Siewers, U. (2001).** The chemistry of Norwegian groundwaters: IV. The pH-dependence of element concentrations in crystalline bedrock groundwaters. **The Science of the Total Environment**, 277, 101-117**.**

Appendix A: Extracts from "Hydrogeological Maps: A Guide and a Standard Legend" by W.F. Struckmeier and J. Margat, *International Association of Hydrogeologists (IAH), Contributions to Hydrogeology* Volume 17 (1995).

All strata at outcrop appear in colour on the map, whether aquifers or non-aquifers. Aquifers in which flow is mainly intergranular (mostly unconsolidated material) are coloured blue; fissured aquifers, including karst aquifers, are coloured green. In each case a dark tone of the colour indicates large and extensive groundwater resources and a high productivity of the aquifer, while a lighter tone indicates local and smaller resources and a lower productivity. Formations containing only limited or local groundwater resources are coloured light brown, while strata with essentially no groundwater are coloured dark brown. The colours, therefore, combine information on the occurrence of groundwater with information on groundwater flow regimes. This information is essential for the recognition of the hydrogeological units occurring in the mapped area.

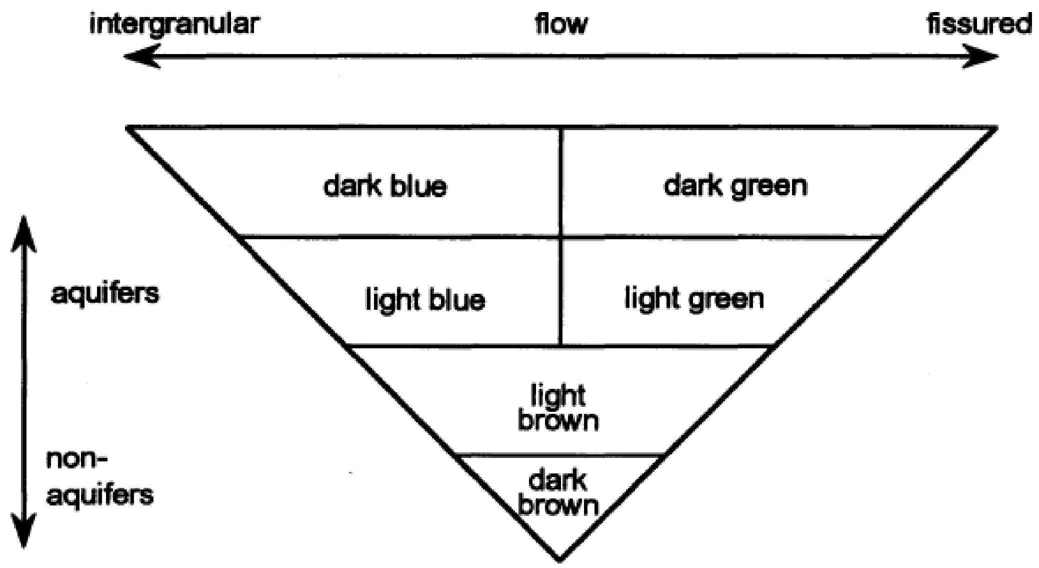


Figure II-1. Scheme of areal colours to represent hydrogeological characteristics and occurrence of groundwater.

Depending on the purpose and scale of the map it may be useful to omit relatively thin covering layers (e.g. 10 - 20 m), to be allow clear map information on the underlying aquifers.

Hatching with fine, vertical, brown stripes is used where thin covering layers of low permeability overlie major aquifers or groundwater systems. Reference to this type of representation should be made in the Legend.

INTERNATIONAL STANDARD LEGEND (English)

Section I General and special hydrogeological maps

I A Background information

1 All background information is printed in screened black with the exception of the simplified topographic base map which is printed in dark grey (60 % black). It shows mainly the location and names of important localities and geographic names, international and administrative boundaries.

2 The drainage (stream or river) network is printed in blue.

3 Grids or lines of longitude and latitude are printed in black.

4 Additional background information to topography and orography where required is given on insert maps or in the explanatory notes.

I B Groundwater and rocks

1 Aquifers in which flow is mainly intergranular

1.1 extensive and highly productive aquifers

1.2 local or discontinuous productive aquifers or extensive but only moderately productive aquifers

2 Fissured aquifers, including karst aquifers

2.1 extensive and highly productive aquifers

2.2 local or discontinuous productive aquifers, or extensive but only moderately productive aquifers

3 Strata (granular or fissured rocks) forming insignificant aquifers with local and limited groundwater resources or strata with essentially no groundwater resources

3.1 minor aquifers with local and limited groundwater resources

3.2 strata with essentially no groundwater resources

3.3 where there is an extensive aquifer immediately underlying a thin cover the appropriate aquifer colour should be used crossed by brown stripes (one mm wide and three mm separation)

Note: Certain aquifers combine intergranular and fissure characteristics. In such cases the relevant colours described in sections 1 and 2 should be used depending on which characteristic is dominant, or another tone of colour (e.g. a bluish green) may be added.

I C Lithology

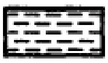
Ornament indicating lithology is printed in grey.

The orientation of the ornament indicates the type of bedding:
horizontal = unfolded, horizontal or gently inclined strata
vertical = folded strata

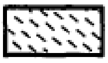
The following list contains ornaments which indicate general lithological types as well as some combinations to symbolize strata of varying lithology.

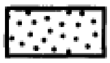
Recommended ornaments

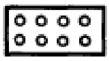
Lithology of sedimentary rocks

 1 clay, clayey loam, mud, silt, marl

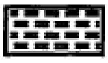
 2 clayey-loamy alteration products

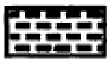
 3 loess

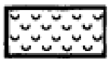
 4 sands (units can be distinguished by variation of thickness of points)

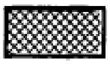
 5 gravels (distinction by varying the arrangement of circles)

 6 moraines

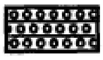
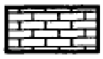
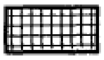
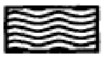
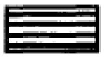
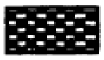
 7 peat

 8 lignite

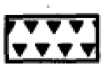
 9 pyroclastics

 10 made ground

11-19 additional ornaments

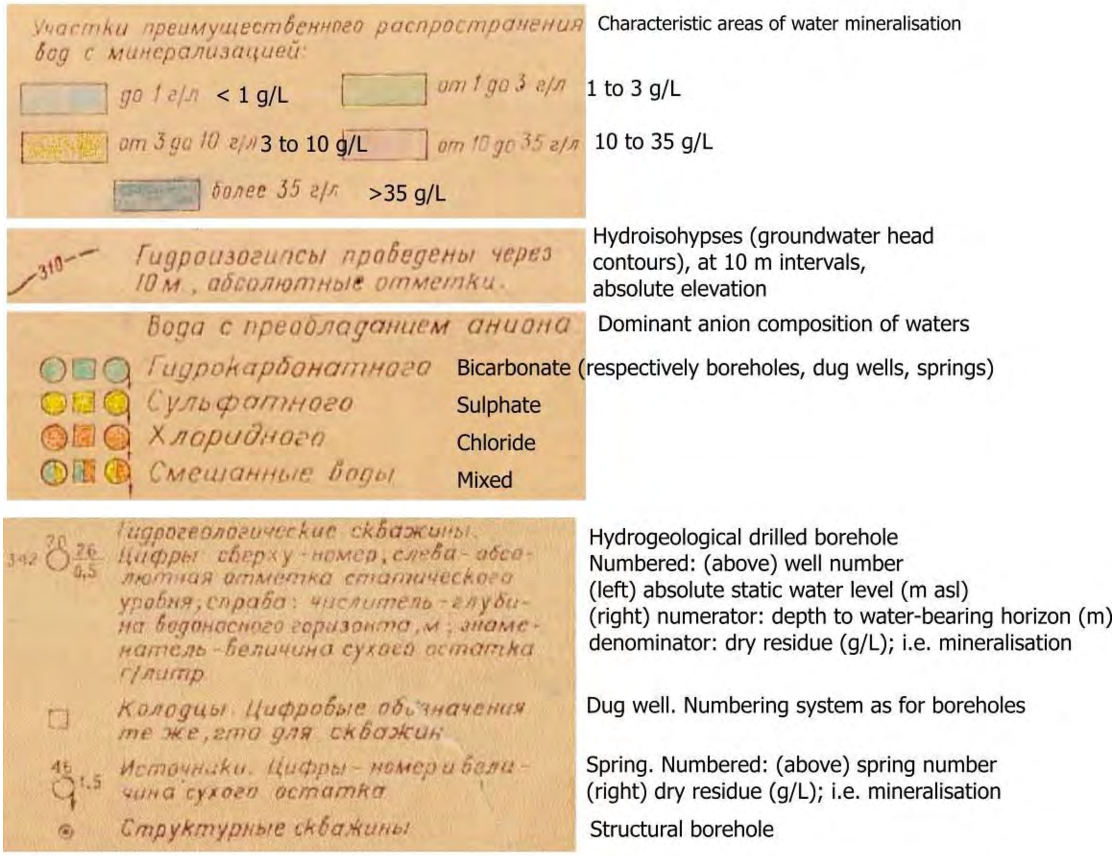
	20	mudstone, siltstone, shale
	21	sandstone (distinction by varying the size of dots)
	22	conglomerate
	23	limestones (distinction by varying the rectangle size)
	24	dolomites (distinction by varying the parallelogram size)
	25	travertine
	26	marlstone
	27	flysch
	28	complex alternation of different lithologies
	29	radiolarite, lydite, siliceous shale
	30	rock salt
	31	gypsum
	32-39	additional ornaments

Lithologies of igneous and metamorphic rocks

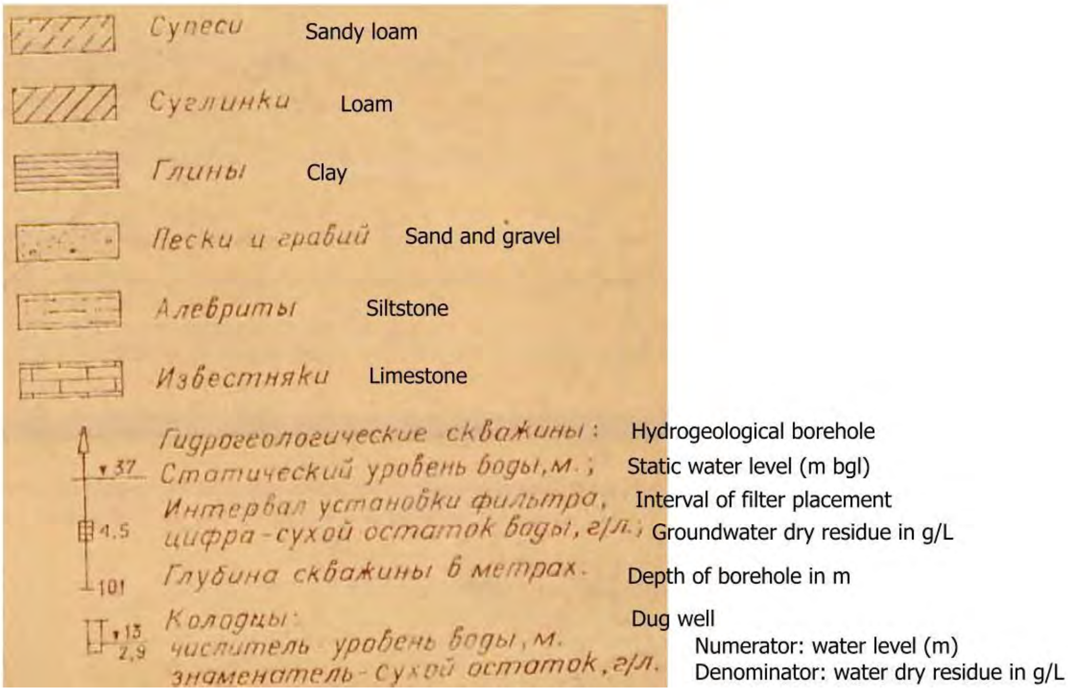
	40	acid to intermediate extrusives (distinction by varying the triangle size)
	41	basic extrusives (distinction by varying the triangle size)
	42	ultrabasite, serpentinite

Appendix B: Key to Mishkin's (1968) Hydrogeological Map of northern Afghanistan

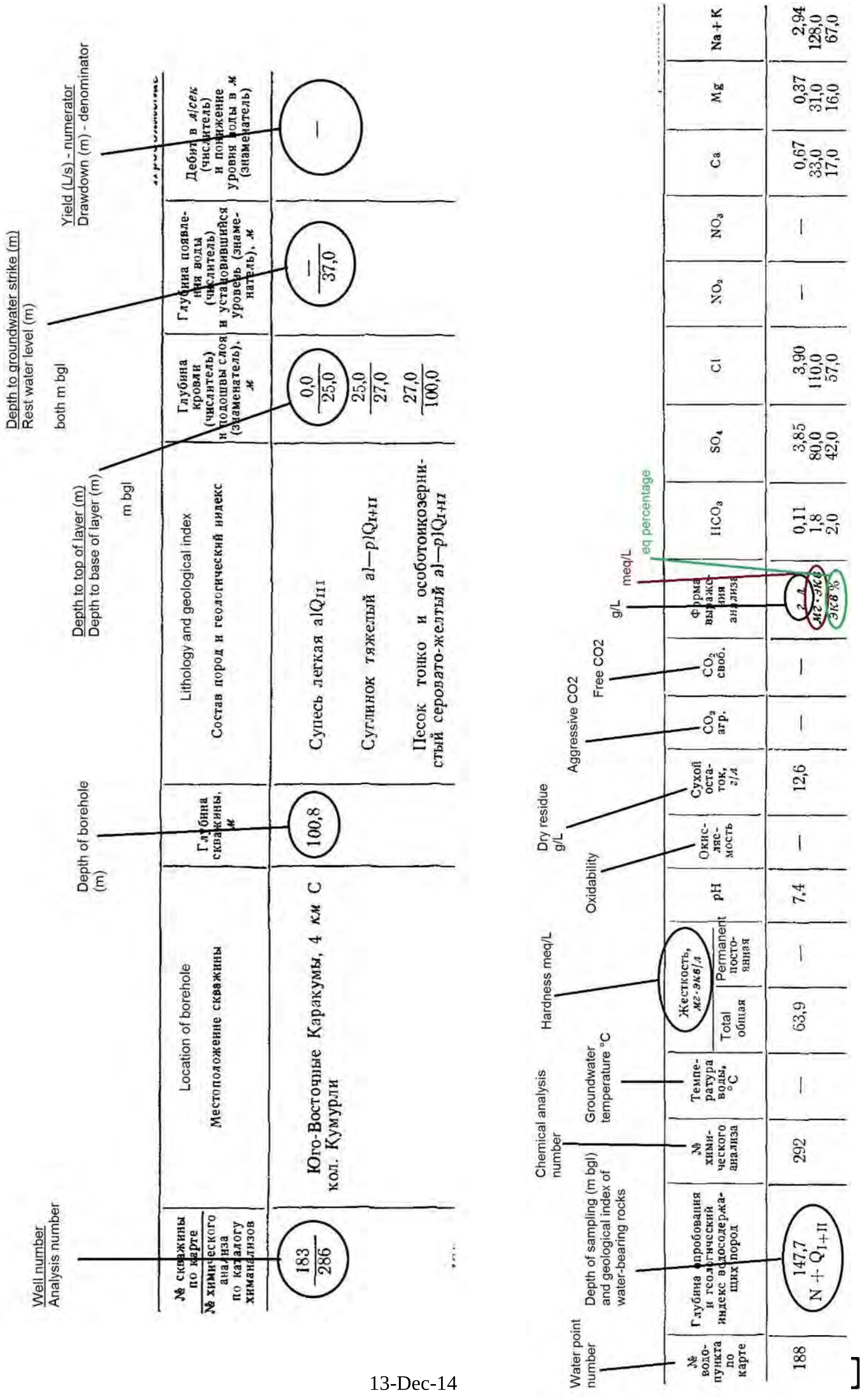
Map legend



Section legend



Appendix C: Key to Tables in Vol. 38 (Turkmenistan) of the Hydrogeology of the Soviet Union



№ скважины по карте / № химического анализа по каталогу химанализов	Местоположение скважины	Глубина скважины, м	Состав пород и геологический индекс	Глубина кровли (числитель) и подошвы слоя (знаменатель), м	Глубина появления воды (числитель) и установившийся уровень (знаменатель), м	Дебит в л/сек (числитель) и понижение уровня воды в м (знаменатель)
183/286	Юго-Восточные Каракумы, 4 км С кол. Кумурли	100,8	Супесь легкая alQ_{III}	0,0/25,0	—/37,0	—
			Суглинок тяжелый $al{-}plQ_{I+II}$	25,0/27,0		
			Песок тонко и особотонкозернистый серовато-желтый $al{-}plQ_{I+II}$	27,0/100,0		

№ водопункта по карте	Глубина опробования и геологический индекс водосодержащих пород	№ химического анализа	Температура воды, °C	Жесткость, мг·экв/л: общая	Жесткость, мг·экв/л: постоянная	pH	Окисляемость	Сухой остаток, г/л	CO_2 агр.	CO_2 своб.	Форма выражения анализа	HCO_3	SO_4	Cl	NO_2	NO_3	Ca	Mg	Na + K
188	147,7 $N+Q_{I+II}$	292	—	63,9	—	7,4	—	12,6	—	—	г/л	0,11	3,85	3,90	—	—	0,67	0,37	2,94
											мг·экв	1,8	80,0	110,0			33,0	31,0	128,0
											экв %	2,0	42,0	57,0			17,0	16,0	67,0